PB86-108271

Transfer Efficiency of Improperly Maintained or Operated Spray Painting Equipment Sensitivity Studies

Centec Corp., Reston, VA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Sep 85

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

EPA-600/2-85-107

September 1985

PB86-108271

EPA

Research and Development

TRANSFER EFFICIENCY OF IMPROPERLY MAINTAINED OR OPERATED SPRAY PAINTING. EQUIPMENT SENSITIVITY STUDIES

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA/600/2-85/107

2.

3. RECIPIENT'S ACCESSION NO.
PB86 108271

4. TITLE AND SUBTITLE
Transfer Efficiency of Improperly Maintained or Operated Spray Painting Equipment Sensitivity Studies

5. REPORT DATE
September 1985

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
K. C. Kennedy

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Centec Corporation
11260 Roger Bacon Drive
Reston, Virginia 22090-5281

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-03-1721, Task 1

12. SPONSORING AGENCY NAME AND ADDRESS
EPA, Office of Research and Development
Air and Energy Engineering Research Laboratory
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED
Task Final; 6/83 - 6/85

14. SPONSORING AGENCY CODE
EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Charles H. Darvin, Mail Drop 54, 919/541-7633.

16. ABSTRACT
The report gives results of an investigation of the impact of common industrial operating and maintenance practices on the efficiency of spray painting systems. The investigation included independent research, as well as assistance from both representatives of the spray painting equipment manufacturing industry and users of spray painting equipment. The results indicate strong directional response in painting efficiency to certain common painting practices.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Spray Painting	Stationary Sources	13H
Maintenance	Transfer Efficiency	15E
Operations		14G

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 163
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

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EPA/600/2-85/107
September 1985

TRANSFER EFFICIENCY OF IMPROPERLY MAINTAINED OR OPERATED SPRAY PAINTING EQUIPMENT SENSITIVITY STUDIES

by

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Contract Number 68-03-1721, Task 1

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on the environment and even on health often require that new and increasingly more efficient pollution control methods be used. The Air and Energy Engineering Research Division (AEERD) at Research Triangle Park, North Carolina, assists in developing and demonstrating new and improved methodologies that will meet these needs both effectively and economically.

The research described herein was undertaken to address how spray painting transfer efficiency is affected by operating and maintenance parameters. Air pollution impacts, energy, and materials resource conservation are affected by loss of paint and solvent in poorly operated or maintained spray painting facilities.

Four major types of spray painting equipment were tested to determine their sensitivity to certain preselected operating or maintenance parameters.

This is the first published research into a very expensive industrial and environmental problem.

ABSTRACT

This report is submitted in fulfillment of Contract Number 68-03-1721, Task 1. It describes sensitivity studies conducted on four types of spray systems to determine the effects of improper operations or maintenance on transfer efficiency. A Draft Standard Transfer Efficiency Method was used for the test program. Three different target configurations were painted for each spray system.

Test results show the strong effect proper selection of spray conditions has on transfer efficiency. The particular level of response for specific factors varies from spray system to spray system, and from target configuration to target configuration. Case-specific regressions were developed for each spray system and target type. These are presented and discussed in the report.

CONTENTS

Disclaimer ii
Foreword iii
Abstract iii
Figures vii
Tables viii
Abbreviations and Symbols x
Acknowledgment xi

1. Introduction 1
2. Conclusions 3
3. Mass Flow Rate Comparison 4
4. Air Atomized Conventional Spray Equipment 7
    - Equipment Description 7
    - Operating and Maintenance Variables 8
    - Experimental Design 10
    - AAC Test Performance 13
    - Test Results 17
    - Statistical Analysis 17
    - AAC Test Conclusions 25
5. Air Atomized Electrostatic Spray Equipment 30
    - Equipment Description 30
    - Operating and Maintenance Variables 31
    - AAE Test Performance 38
    - Test Results 40
    - Statistical Analysis. 40
    - AAE Conclusions 44
6. Airless Conventional Spray Equipment 50
    - Equipment Description 50
    - Operating and Maintenance Variables 50
    - Experimental Design 52
    - Test Performance 52
    - Test Results 56
    - Statistical Analysis 56
    - ALC Conclusions 59
7. Airless Electrostatic Spray Equipment 64
    - Equipment Description 64
    - Operating and Maintenance Variables 65
    - Experimental Design 65
    - ALE Test Performance 70
    - Test Results 73
    - Statistical Analysis 75
    - ALE Conclusions 77

CONTENTS (Continued)

8. Comparison of Targets 83
Background 83
Comparison of Variables Identified as Significant 83
Worth Assessment of Three Target Configurations . 85

Appendices

A. Draft Standard Method for Spray Painting Transfer Efficiency Operations and Maintenance Testing 87
B. Quality Assurance/Quality Control Plan Sensitivity Studies on the Effects on Transfer Efficiency of Improperly Maintained or Operated Spray Painting Equipment 114
C. AAC Test Equipment and Paint Specifications 136
D. AAE Test Equipment and Paint Specifications 139
E. ALC Test Equipment and Paint Specifications 142
F. ALE Test Equipment and Paint Specifications 145
G. Glossary of Statistical Terms 148

FIGURES

Number Page

1 Air atomized conventional air cap (frontal view) 16

2 Air atomized electrostatic air cap (frontal view) 33

3 Air atomized electrostatic electrode position test levels. 34

4 Airless paint spraying system. 51

5 Airless electrostatic air cap showing test levels for electrode position.. 72

A-1 Target configurations for air atomized conventional and electrostatic spray guns. . . 90

A-2 Target configuration for high speed bell . . . 91

A-3 Set-up for paint supply equipment and platform scales 97

A-4 Permissible methods for measuring conveyor speed. 101

A-5 Vertical cylinder wrapping technique 105

A-6 Flat panel foil attachment technique 106

B-1 Project organization as related to corporate structure. 120

B-2 Data validation responsibilities 127

TABLES

Number Page

1 Mass Flow Comparison Data 5
2 Operating and Maintenance Variables for AAC Spray Equipment 9
3 Experimental Variables Selected for Testing AAC Spray Systems 10
4 AAC Experimental Design 11
5 Levels of Operating and Maintenance Variables Tested on AAC Spray Painting Equipment 15
6 Air Atomized Conventional Test Results 18
7 AAC F-Statistics and Associated Probability . . 21
8 AAC-FP Comparison of Predicted Versus Actual Transfer Efficiencies 26
9 AAC-VC Comparison of Predicted Versus Actual Transfer Efficiencies 27
10 AAC-Graco Comparison of Predicted Versus Actual Transfer Efficiencies 28
11 Operating and Maintenance Variables for AAE Spray Equipment 32
12 Operating and Maintenance Variables for AAE Spray Painting Equipment 36
13 AAE Experimental Design 37
14 Levels of Operating and Maintenance Variables Tested on AAE Spray Painting Equipment 39
15 AAE Test Results 41
16 AAE F-Statistics and Associated Probability . . 46
17 AAC-FP Comparison of Predicted Versus Actual Transfer Efficiencies 47
18 AAC-VC Comparison of Predicted Versus Actual Transfer Efficiencies 48
19 AAC-Graco Comparison of Predicted Versus Actual Transfer Efficiencies 49
20 Levels of Operating and Maintenance Variables Tested on ALC Spray Painting Equipment. 53
21 ALC Experimental Design 54
22 Order of Performance of ALC Test Runs 55
23 ALC Test Results 57
24 ALC F-Statistics and Associated Probabilities . 59
25 ALC-FP Comparison of Predicted Versus Actual Transfer Efficiencies 60

TABLES (Continued)

Number Page

26 ALC-VC Comparison of Predicted Versus Actual Transfer Efficiencies 61
27 ALC-Graco Comparison of Predicted Versus Actual Transfer Efficiencies 62
28 Operating and Maintenance Variables for ALE Spray Equipment 66
29 Experimental Variables Selected for Testing ALE Spray Equipment 68
30 ALE Experimental Design 69
31 Levels of Operating and Maintenance Variables Tested on ALE Spray Painting Equipment 71
32 ALE Test Results 74
33 ALE F-Statistics and Associated Probabilities . 78
34 ALE-FP Comparison of Predicted Versus Actual Transfer Efficiencies 79
35 ALE-VC Comparison of Predicted Versus Actual Transfer Efficiencies 80
36 ALE-Graco Comparison of Predicted Versus Actual Transfer Efficiencies 81
37 Comparison of Significant Factors Identified by Three Target Configurations 84
38 Worth Assessment Model Comparing Target Configurations 86

A-1 Nomenclature for Spray Painting Transfer Efficiency Tests 104
B-1 Spray Painting Transfer Efficiency Precision, Accuracy and Completeness Objective 122

B-2 Performance Audit Requirements 132

LIST OF ABBREVIATIONS AND UNIT CONVERSIONS

ABBREVIATIONS

ASTM -- American Society for Testing and Materials
AAC -- air atomized conventional paint spray equipment
AAE -- air atomized electrostatic paint spray equipment
ALC -- airless conventional spray equipment
ALE -- airless electrostatic spray equipment
EPA -- United States Environmental Protection Agency
Fan air -- shaping air or horn air
FP -- flat panel (target configuration)
PSIG -- pounds per square inch, lb/in^2, gauge
O&M -- operating and maintenance
QA/QC -- quality assurance/quality control
TE -- transfer efficiency
VC -- vertical cylinder (target configuration)
VOC -- volatile organic compounds

UNIT CONVERSIONS

To go from	To	Multiply by
°C	°F	1.8°C + 32
cm	in	2.54
g	lb	0.0022
kg	lb	2.204
kg/L	lb/gal	8.328
kPa	psig	0.145 kPa -14.7
L	gal	0.264
m	ft	3.281
m	mils	3.937 x 10^4
m/s	ft/min (fpm)	196.85
m^3/s	ft^3/min	2118.8
rps	rpm	0.017
s	min	60.0

ACKNOWLEDGEMENT

The contributions of Graco, Incorporated are gratefully acknowledged. Graco donated laboratory facilities, test equipment and supplies, and provided technical support for the tests described herein.

The knowledge and experience of [redacted] Ray Myers, Professor of Statistics at Virginia Polytechnic Institute and State University and author of "Response Surface Methodology" and "Probability and Statistics for Engineers and Scientists," was invaluable to this effort. [redacted] Myers developed the experimental design and evaluated the test data using the Statistical Analysis System. [redacted] Myers' contributions as a statistical consultant are gratefully acknowledged.

SECTION 1

INTRODUCTION

This test program was initiated to develop information about how spray painting transfer efficiency (TE)* is affected by operating and maintenance variables. Four basic types of spray equipment were selected for the test program: air atomized conventional (AAC), air atomized electrostatic (AAE), airless conventional (ALC), and airless electrostatic (ALE).

Operating and maintenance (O&M) variables were developed for each of these equipment types through a literature search, by industry contacts, and through manufacturers of spray equipment. Over thirty separate variables were identified. Based on an evaluation of the possible effect of each variable on TE (for each type of equipment) and on the ability to simulate the variable in a laboratory, the most significant variables were selected for testing in this program. Up to 7 variables were selected for testing on a single equipment type.

An experimental design was developed to address selected operating and maintenance variables for each type of equipment. In each case the design consisted of a fractional factorial design augmented by a "star" design and a set of replicates. The process of identification of operating and maintenance variables, and of developing appropriate experimental designs is detailed in "Subtask Report: Sensitivity Studies on the Effects on Transfer Efficiency of Improperly Maintained or Operated Spray Painting Equipment." Levels for testing each variable were developed on-site prior to testing.

Once the test program was well defined, CENTEC began contacting companies with well equipped spray painting laboratories to locate a qualified test site. The electrostatics laboratory at Graco, Incorporated in Minneapolis, Minnesota, was qualified and willing to participate in the test program. Graco provided the laboratory, spray equipment, technicians, and some other materials for testing.

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*TE is the amount of paint solids deposited on a target divided by the amount of paint solids sprayed at the target multiplied by 100 percent.

The test program was conducted in February 1984. Each equipment type was the subject of a single experiment consisting of up to 34 test runs. Each experiment lasted one week, for a total of 4 weeks of testing. Sections 4, 5, 6, and 7 of this report describe the performance and results of each experiment. Section 2 summaries the overall conclusions from the test program and accompanying test results.

As described in the Draft Standard Test Method (Appendix A), all tests took place with two target types, flat panel (FP) and vertical cylinder (VC). Graco has, for their own purposes, developed a transfer efficiency determination method utilizing a different target design. In all of the testing described in the report, the "EPA" targets (Standard Test Method Targets) were first painted at a given set of conditions, followed by painting the Graco target set under the same conditions. Thus all transfer efficiency results in this report are reported according to flat panel, vertical cylinder, and Graco target results.

SECTION 2

CONCLUSIONS

EFFECTS OF OPERATING AND MAINTENANCE VARIABLES ON TE

AAC transfer efficiency was most strongly affected by restricted air lines. This effect was pronounced over all three target types tested, and should be considered the most prominent O&M variable tested for this type of spray system. Fan air adjustments had a strong effect for two of three target types, and should be considered a major effect as well. Restricted paint lines and booth air rates had significant effects, although not as strong as restricted air lines or fan air.

AAE tranfer efficiency was effected by the highest number of variables. The most prominent effect was voltage, followed by restricted air lines and restricted paint lines. Booth air, gun cleanliness, fan air, and electrode position also had significant effects. These effects were not consistent across all target configurations; the VC and Graco target configurations were much more sensitive to AAE test variations than FP targets. The FP target restricts the ability of electrostatic spray to wrap around and increase TE.

ALC transfer efficiency was overwhelmingly affected by tip erosion. Restricted paint lines were found significant for Graco targets, but the effect of tip erosion was overriding in all cases.

ALE transfer efficiency effects are similar to both the AAE and ALC systems: voltage and electrode position had the largest effects, but effects of other factors were contingent on target configuration.

OTHER CONCLUSIONS

The Graco target configuration was found to be the most sensitive target design for detecting O&M effects. Transfer efficiency regressions had the tightest fit for Graco results, and the target configuration was the most comfortable to use experimentally. Thus, the Graco target represents the most desirable target design tested to date. It is recommended as the standard target for all future TE tests.

SECTION 3

MASS FLOW RATE COMPARISON

The original test method called for determining the paint mass flow rate using platform scales and a stopwatch. (Refer to Appendix A.) The paint supply pot rested on platform scales, and readings were taken as the paint flow was initiated and stopped for each test run. A stopwatch was used to time the interval between scale readings. Mass flow rate was determined by dividing the total weight difference by the elapsed time. While this method had proven satisfactory in determining paint mass flow for TE testing, no airless spray equipment had been tested. Airless pumps create vibration problems in using platform scales. Several sources recommended using a mass flow meter to determine paint flow rate. These sources maintained that a mass flow meter would be simpler to use, easier to read, and more precise than the platform scale/stopwatch method. A mass flow comparison test was designed to evaluate the benefits and any QA/QC implications of these two measurement techniques.

The QA/QC plan for the TE test program specified requirements for determining paint mass flow in terms of weight and time measurements. To ensure that the mass flow meter met these requirements, a test was set up to directly compare methods. The platform scale was set up, calibrated, and zeroed. The paint supply pot was placed on the scales. The paint flow was routed through the mass flow meter, which was also zeroed and calibrated. TE test runs were simulated by spraying atomized paint into an empty spray booth using AAC spray equipment. A test run time of 16 seconds was selected, similar to the time for earlier runs at TE testing sites elsewhere.

Seven test runs were performed. In each run mass flow meter and platform scale/stopwatch readings were taken simultaneously. The experimental results are presented in Table 1. It is readily apparent from Table 1 that the standard deviation of the mass flow meter data was significantly lower than for the original mass flow determination method, while the average mass flow rates were virtually identical.

Table 1 presents the results of seven experiments performed to compare flow rates as determined by the the mass flow meter and by the platform scale/stopwatch method. The use of the platform scale and stopwatch is described in the Draft Standard Test Method and has been used in all testing to date. The use of the mass flow meter would offer certain simplifications in the proposed test procedure. The experiments listed in Table 1 were undertaken, then, to determine if the two flow rate measurement methods gave substantially equivalent results in order to justify the subsequent use of the mass flow meter.

TABLE 1. MASS FLOW COMPARISON DATA

Experiment number	Platform scale & stopwatch method, g/s	Mass flow meter, g/s
1	10.16	9.99
2	10.05	9.99
3	10.09	9.99
4	9.96	9.99
5	10.04	9.99
6	9.74	9.91
7	9.93	9.93
Mean	10.00	9.97
Standard Deviation	0.14	0.03

It was determined that the new method would be accepted if it provided readings within the accuracy specifications set for the flow rate determination, ±2 percent. The standard deviation of the flow rate determination by scale and stopwatch had been estimated to be 0.1 g/s. At a flow rate of 10 g/s, then, a maximum acceptable difference of 0.2 g/s was set, or a ratio of acceptable difference to standard deviation of 2.0.

The risk of falsely accepting the mass flow meter as meeting these criteria, the β-risk, was set at 0.05. That is, no more than a 5 percent risk was desired that the sample would be judged to have come from an acceptable population when it really came from an unacceptable population. The α-risk, or the risk that the two methods might be judged different when they actually are equivalent, was set at 0.1 (double-sided test).

The required number of observations to control the α and β-risks to these levels under the stated conditions is seven. The significance of the difference between the means was then determined by performing a t-test at the 0.1 level.

The t-statistic as determined for the data of Table 1 is 0.458 with 12 degrees of freedom. Since the value of t is well below the critical value at the 0.1 level, it may be stated that the two methods do not differ by more than 0.2 g/s at the stated levels of risk.

SECTION 4

AIR ATOMIZED CONVENTIONAL SPRAY EQUIPMENT

EQUIPMENT DESCRIPTION*

A Graco Model 800 manual air spray gun was selected for AAC testing. The Model 800 gun was considered typical of pressure-fed external mix air spray equipment. The spray gun was equipped with a 021-106806 Graco air cap, and a 1.2 mm fluid tip. Paint flow was manually initiated by opening a valve on the paint supply line. Paint flow was measured by a daily-calibrated Micromotion mass flow meter (see Section 3).

A standard Graco black enamel was selected as the test paint. The paint averaged about 28 weight percent solids during AAC tests and was adjusted to 29 seconds (#2 Shell cup) viscosity. A 16 L (4 gal) batch of paint was mixed for AAC testing. One batch was sufficient to complete AAC testing. Paint was mixed and stored in a 20 L (5 gal) Graco Model 210-393 pressure tank, which was kept in a temperature-controlled booth. The paint pressure tank, stirrer, regulators, viscosity measurement equipment, and some supply lines were kept in the temperature-controlled booth at 25°C ± 1°C throughout TE testing. All paint supply lines (spanning 6-8m) were insulated.

AAC tests were conducted in a Dynaprecipitator water wash spray booth. Air flow was in the direction of paint spray, normal to the targets. Air flow was adjusted by opening or closing a vent on the booth exhaust duct. With the vent closed, the booth air rate was 61 cm/s (120 fpm) at the plane of the targets, and varied from 51 cm/s to 71 cm/s (100 fpm to 140 fpm) across the booth face during testing. With the vent open, the booth fan pulled air directly from the room and through the booth (instead of taking suction from the booth alone), lowering the booth air flow rate to 36 cm/s (70 fpm) and varied from 25 cm/s to 46 cm/s (50 fpm to 90 fpm) across the booth face during testing. Targets were kept from being blown back from the spray equipment by a polymer pipe frame mounted between the targets and the water wash.

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*Air atomized conventional (AAC) spray equipment is characterized by the use of air as the atomizing agent for the paint spray.

A variable-speed electric conveyer system (Reliance Electric Company) was used to carry the targets in front of the spray equipment. All AAC runs were made with the conveyor set at 10.6 cm/s. Very little fluctuation was observed in conveyor speed during AAC testing.

Foil weights were determined on Precisa laboratory scales accurate to 0.01 g. Weight-percent-solids samples and dishes were weighed on 0.0001 g accuracy laboratory scales.

A forced air gas-fired oven was used for curing weight percent solids samples and painted foil TE samples. TE samples were mounted on a large rack for curing, while weight percent solids sample dishes were placed on a makeshift shelf for curing. Both were cured at 148.9°C (300°F) for 20 minutes. After the first few TE samples showed signs of contamination (dirt flecks in finish), the oven was cleaned out daily by vibrating the walls and then vacuuming.

A Micro Motion mass flow meter was used for paint mass flow determinations. Section 3 discusses the use of a mass flow meter in comparison to the digital scales/stopwatch mass flow determination method specified in the test procedure (Appendix A).

Medium temper 4×10^{-5}m (1.5 mil) thick, 15.24 cm (6 in) wide aluminum alloy foil was used to cover VC and FP targets. (Refer to Appendix A, Test Method.) Medium temper 4×10^{-5} m (1.5 mil) aluminum alloy foil 38.1 cm (15 in) wide was used to cover Graco targets during testing.

The test method in Appendix A was strictly adhered to for AAC testing, as were the QA/QC requirements of Appendix B. After each EPA test run was completed, a separate run was made using Graco targets. A summary of all AAC test equipment specifications is presented in Appendix C.

OPERATING AND MAINTENANCE VARIABLES

During an earlier phase of this project, industry representatives, consumers, and manufacturers identified 17 operating and maintenance variables considered important in achieving optimum TE for AAC equipment. These variables are listed in Table 2.

Five variables were selected for testing on the basis of the number of times it was identified by different sources, the anticipated size of effect on TE, the ability to simulate it within the prescribed test methodology, and finally, the limitation of laboratory time. The five selected test variables were:

- Restricted air lines
- Booth air rate
- Gun cleanliness
- Restricted paint lines
- Fan (or horn) air

TABLE 2. OPERATING AND MAINTENANCE VARIABLES FOR AAC SPRAY EQUIPMENT*

Atomizing air

Booth air rate

Booth configuration

Cure schedule (time, temperature)

Paint discharge technique

Equipment design

Flash off

Gun cleanliness

Gun condition

Gun-to-target distance

Operator error

Paint mass flow rate

Paint characteristics

Restricted air supply

Restricted paint supply

Shaping air (fan air)

Target configuration

* As mentioned by industry sources contacted

Some of the variables could be quantitatively simulated (for example by varying paint pressure), while others could only be simulated qualitatively.

EXPERIMENTAL DESIGN

An experimental design was developed to accommodate the limitations of testing while addressing the effects of each variable as completely as possible.

The first restraint on experimental design was the availability of laboratory time: only about 30 test runs could reasonably be completed during a week of testing. The second limitation was the number and type of simulation levels for each variable. Only two levels of linear air velocity (booth air rate) were possible in the test laboratory, while three levels of fan air (sometimes called horn air or shaping air) were achievable, and five or more levels of the other variables could be simulated. Table 3 presents the type of variable (quantitative/qualitative) and levels to be accommodated in the experimental design.

TABLE 3. EXPERIMENTAL VARIABLES SELECTED FOR TESTING AAC SPRAY SYSTEMS

Factor ID	Factor description	Quant./ qual.	No. of test levels
A	Restricted atomizing air lines	Quant.	5
B	Booth air rate (linear velocity)	Quant.	2
C	Gun cleanliness	Qual.	5
D	Restricted paint lines	Quant.	5
E	Fan air (sometimes called horn air or shaping air)	Qual.	3

A central composite experimental design was selected as the most thorough way to examine the effects of these factors with the fewest number of test runs. The experimental design is characterized by combining a fractional factorial design portion with a "star" portion, augmented by replicates.

Table 4 presents the AAC experimental design. In this table, the abbreviations "a," "1," "0," "-1," and "-a" denote

TABLE 4. AAC EXPERIMENTAL DESIGN

			FACTOR		
Run Number	A	B	C	D	E
1	-1	-1	-1	-1	1
2	-1	-1	-1	1	-1
3	-1	-1	1	-1	-1
4	-1	1	-1	-1	-1
5	1	-1	-1	-1	-1
6	1	1	1	-1	-1
7	1	1	-1	1	-1
8	1	1	-1	-1	1
9	1	-1	1	1	-1
10	1	-1	1	-1	1
11	1	-1	-1	1	1
12	-1	1	1	1	-1
13	-1	1	1	-1	1
14	-1	1	-1	1	1
15	-1	-1	1	1	1
16	1	1	1	1	1
17	-a	-1	0	0	0
18	a	-1	0	0	0
19	0	1	-a	0	0
20	0	1	a	0	0
21	0	-1	0	-a	0
22	0	-1	0	a	0
23	0	1	0	0	-1
24	0	1	0	0	1
25	a	1	a	a	1
26	a	1	a	a	1
27	a	1	a	a	1
28	a	1	a	a	1
29	a	1	a	a	1
30	a	1	a	a	1

Where:

A = Restricted air lines--test at 5 levels: a,1,0,-1,-a
B = Booth air rates--test at 2 levels: 1,-1
C = Gun cleanliness--test at 5 levels: a,1,0,-1,-a
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
E = Fan air--test at 3 levels: 1,0,-1

the level of each variable to be tested. Level "a" denotes the base level with a good spray pattern. Level "-a" denotes the poorest level of a variable to be tested. The intermediate levels "1," "0," and "-1" were determined along equal spacing from "a" to "-a" for the particular variable. Level "a" will be different for each experimental design and for different variables in the design. It remains constant for a given variable in a given design.

Levels for AAC variables were determined in pretest trials as described in the following subsection.

The first 16 test runs in the experimental design (Table 4) are the fractional factorial portion of the design. When the results of several factors are to be studied, a factorial design is usually the most efficient method to use.* The basic idea of factorial design is to alter several aspects of a test at a time, but in such a way that the effects of individual alterations can be determined. Fractional factorial designs sacrifice some ability to test for interaction between factors but are able to test for main effects very efficiently.

Runs 17 through 24 in Table 4, are the "star" portion of the experimental design. This portion of the experiment tests the effects of variables at the extremes of their range (for the system under test, at "a" and "-a"). The star design broadens the range of information gathered in the test. The star portion of the design allows extra degrees of freedom in order to assess lack of fit.

The experimental design used in the AAC case involves a central composite design for factors A, C, and D. A classical central composite design on all five variables was impossible because of the necessity of using only 2 levels of variable B and 3 levels of variable E.

The last six runs of the test design are replicates. Replicates are provided at the base condition of all variables to provide a measure of the test precision.

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*Youden, W. J. and Steiner, E. H., Statistical Manual of the Association of Official Analytical Chemists, Arlington, VA, 1982; and Davies, O. L., Design and Analysis of Industrial Experiments, Great Britain, 1979; and Myers, Raymond H., Response Surface Methodology, 1976.

AAC TEST PERFORMANCE

AAC testing began on February 8, 1984. Equipment set up, target assembly and hanging, foil cutting and preweighing, and other preparatory activities were completed earlier in the week. The morning of February 8 was spent mixing and adjusting test paint to desired specifications. (See Appendix C for paint specifications.) About 16 L (4 gal) of paint was mixed in the 20 L (5 gal) capacity paint pressure pot. The paint was stored inside a temperature-controlled booth at 25°C ± 1°C. Once the paint was adjusted, all equipment and lines were rechecked for proper installation and freedom from obstruction. The mass flow meter was calibrated and zeroed. Mass flow calibration was double checked against unatomized paint capture and found to be within 0.4 percent of the meter reading, as required.

Preliminary paint weight-percent-solids determinations were made using the recommended ASTM method, and using Graco's own technique. (The ASTM method is included in Appendix A.) Basically, the ASTM method required sampling the paint and adding 0.5 g (± 0.1 g) of the paint sample to a dry preweighed 58 mm aluminum sample dish. Solvent (3 mL) was added to the sample prior to curing to spread the paint sample evenly in the dish. The Graco method required a 15 mL paint sample be taken and spread out by gravity into a 30.48 cm (12 inch) preweighed aluminum dish. The results of the two methods did not closely agree, and some unacceptable variance in the ASTM method was also noted. According to the QA/QC plan, TE data cannot be accepted unless all component measurements meet precision requirements.

A number of weight-percent-solids determinations was made to resolve the differences. In running these samples it was discovered that the ASTM-method aluminum dishes were coated with an oily compound to keep them from sticking together in storage. This coating had to be burned off before the dish could be used in weight-percent-solids determinations. The weight of the oil on the preweighed dish varied, causing the net weight percent solids to vary as well. It was also discovered that uneven distribution of the paint (in either method) caused differences in curing and consequently in weight percent solids. The latter problem manifested itself most frequently in the Graco method, and almost none at all in the ASTM method when proper care was taken to assure the dishes were level during curing. As detailed in the TE test procedure, the ASTM method was used for all EPA weight-percent-solids determinations in this report. Graco amended their weight-percent-solids determination to follow ASTM recommendations, but continued to take their weight-percent-solids samples from the paint line rather than from the paint pot as the TE test procedure requires. Graco weight-percent-solids samples continued to vary somewhat from EPA values, apparently due to the sampling technique or position. (The term "EPA values" as used here refers to the determinations made following the Draft Standard Test Method of Appendix A.)

While one group of technicians was performing weight-percent-solids determinations, a second group of technicians was setting up the equipment at base levels of each variable. Base level ("a") was determined by Graco experience with the test paint and spray painting system. Selection of base level was confirmed by checking the spray pattern at base level for a good pattern. No adjustments were required from Graco-recommended base levels after checking the spray pattern. Base levels were thus determined as shown in Table 5.

Deteriorated levels were selected by setting all variables, except the subject variable (for each variable in turn), at the base level. The subject variable was altered until a significantly worse spray pattern could be discerned. The spray pattern was checked by spraying onto a paper target for 5 or 6 seconds then observing the resulting pattern. Deteriorated factor levels ("-a") thus determined are shown in Table 5.

Intermediate factor levels were calculated to be evenly spaced from the base level ("a") to the deteriorated level ("-a"). Intermediate levels are also shown in Table 5.

Selection of levels for gun cleanliness were made by trial and error pattern testing of air caps with different holes plugged. The resulting pattern of plugged holes for deteriorating levels of gun cleanliness is shown in Figure 1. Gun cleanliness must be considered qualitative because of the nature of the progressively more plugged air cap. Atomization and TE may be affected as much or more by the geometry and design of the plugged holes than by the total plugged area.

Booth air rates were determined by the only two available levels. Neither level should be assumed to be an ideal level. Base level was selected at the normal air flow level for the booth, rather than the artificially lowered level. Rates at each level were measured using a hot wire anemometer.

Level selection was completed on February 8, 1984. AAC TE testing began on February 9, 1984. TE runs were made in a randomized order based on the experimental design in Table 4. During a single 16-hour experimental day 15 runs were made. Three of the runs were thrown out because of incomplete data, underspray, or losing paint from the targets because of dripping or accidental contact with wet targets. These three runs were repeated at the end of the day.

TE testing of AAC equipment was completed on February 10, 1984, after performing the remaining 15 runs. One run (Run 10) was identified as an outlier by the QA/QC analysis (Refer to Appendix B); it was repeated immediately. Weight-percent-solids samples were taken at the completion of testing as required by the draft Standard Test Method.

TABLE 5. LEVELS OF OPERATING AND MAINTENANCE VARIABLES--TESTED ON AAC SPRAY PAINTING EQUIPMENT

	Factor	Quant/ qual.	No. of levels	Test levels
A.	Restricted automizing air lines*	Quant.	5	a= 239.0 kPa (20 psig) 1= 218.6 kPa (17 psig) 0= 197.9 kPa (14 psig) -1= 177.2 kPa (11 psig) -a= 156.6 kPa (8 psig)
B.	Booth air rate + (linear velocity)	Quant.	2	1= 0.61 m/s (120 ft/min) -1= 0.36 m/s (70 ft/min)
C.	Gun cleanliness †	Qual.	5	See Figure 1
D.	Restricted paint lines	Quant.	5	a= 180.7 kPa (11.5 psig) z 1= 170.3 kPa (10.0 psig) 0= 160.0 kPa (8.5 psig) -1= 149.7 kPa (7.0 psig) -a= 139.3 kPa (5.5 psig)
E.	Fan air #	Qual.	3	1= wide open 0= one turn shut -1= two turns shut

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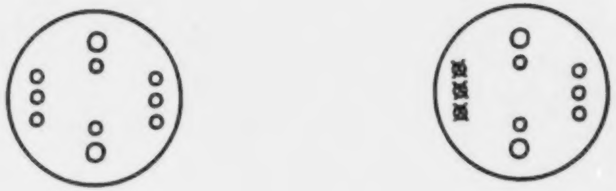
* Measured at the spray gun.

+ Actual booth air rates varied from 100 to 140 ft/min for level "+1" and 50 to 90 ft/min for level "-1." Average air velocities are used in this table.

† Deteriorating gun cleaniness was simulated by blocking air cap holes as shown in Figure 1.

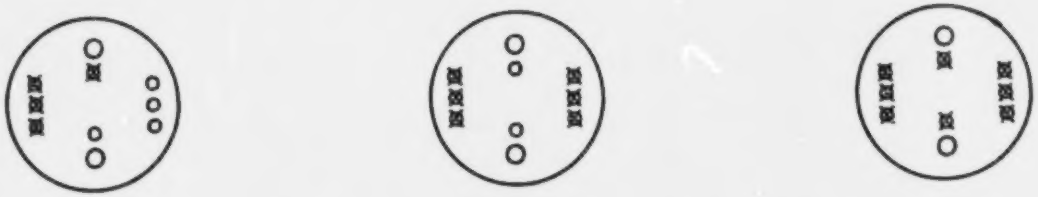
z Measured at control panel approximately 20 feet from spray gun.

# Fan air (sometimes called horn air or shaping air) was adjusted by setting the control knob on the gun wide open, then turning it the required number of turns towards the closed position.



Level +a: all holes open

Level +1: 3 holes plugged



Level 0: 4 holes plugged

Level -1: 6 holes plugged

Level -a: 8 holes plugged

Figure 1. Air atomized conventional air cap (frontal view) showing selection of test levels for gun cleanliness

TEST RESULTS

TE's were calculated according to the Draft Test Standard Method. The final AAC results are presented in Table 6. Some corrections were made to the original TE test data because of mathematical errors or incorrectly recorded weights. These corrections are reflected in Table 6.

STATISTICAL ANALYSIS

Regression equations were developed to fit the TE data for each target design. The regressions developed for AAC equipment are based on the data in Table 6, which were developed according to the experimental design in Table 4. Both qualitative and quantitative variables were coded into the regression analysis according to the level rather than their numerical value during the test. The coding procedure is a simple "centering" and scaling of variable levels. The variable levels for the quantitative variables were evenly spaced. The following represent the coded or "design units."

Quantitative variable level	Coded level for regression equation
a	2
+1	1
0	0
-1	-1
-a	-2

By using these coded values for levels, the regressions become useful for either SI (Le Systeme International d'Unites) or standard U.S. industrial units. Actual test values at different levels than those tested here may be coded by interpolating linearly according to the above table. Thus, a value exactly halfway between "-1" and "-a" would take on the numerical value of -1.5 in the regression equation.

Transformation to design units is standard procedure when one builds models based on a planned experiment involving quantitative variables. It allows for interpretation of regression equation and tests to be in terms of units that are scale free and determined by the region of experimentation selected by the scientist.

Qualitative variable levels were coded in much the same manner, assigning either zero or one to the level for each variable. The "0" level of each qualitative variable was arbitrarily set at zero for all cases in this report. For

TABLE 6. AIR ATOMIZED CONVENTIONAL TEST RESULTS

	Percent Transfer Efficiency		
Run number	FP	VC	Graco
1	62.5	11.9	27.8
2	85.9	15.2	39.9
3	83.8	16.5	41.7
4	77.1	14.6	36.3
5	73.8	13.7	33.2
6	75.8	13.0	34.6
7	77.8	12.3	38.5
8	57.4	11.0	25.8
9	82.0	15.7	38.2
10	58.2	10.7	25.0
11	60.0	9.6	26.1
12	85.3	16.4	38.4
13	61.0	10.7	29.0
14	68.7	13.6	31.4
15	70.7	13.5	32.3
16	65.0	12.6	29.5
17	78.1	15.1	38.9
18	63.5	11.7	30.1
19	66.7	12.2	30.3
20	64.8	11.5	29.5
21	59.5	11.2	28.7
22	73.5	13.7	33.2
23	80.5	15.7	35.9
24	65.7	11.7	28.1
25	58.3	10.3	25.1
26	59.1	11.2	26.2
27	58.4	9.5	26.2
28	58.2	11.2	27.9
29	60.4	11.3	28.3
30	57.1	10.5	25.7

qualitative variables tested at three levels, the value of the variable associated with that particular level is denoted by dummy variables x_nd_1 and x_nd_2, which take on the values:

Factor	Experimental level	Regression level x_nd_1	Regression level x_nd_2
x_n	+1	0	1
x_n	0	0	0
x_n	-1	1	0

Qualitative effects can only be determined on a relative basis. For all of the regressions in this report, the "0" experimental level has been designated the base level of comparision for qualitative O&M factors.

For qualitative variables at five levels, the assignment of regression levels proceeds according to:

Factor	Experimental level	Regression level x_nd_1	x_nd_2	x_nd_3	x_nd_4
x_n	a	0	0	0	1
x_n	+1	0	0	1	0
x_n	0	0	0	0	0
x_n	-1	0	1	0	0
x_n	-a	1	0	0	0

The variables for AAC experiments are designated as follows:

x_1=restricted atomizing air lines

x_2=booth air rate (linear velocity)

x_3=gun cleanliness

x_4=restricted paint lines

x_5=fan air (sometimes called horn air or shaping air)

TE=transfer efficiency

Because x_3 and x_5 cannot be measured on a continuous quantitative scale, they are termed qualitative variables. The various levels of such variables used in the experiment are represented in the analysis of variance and the regression analysis by "dummy variables." Thus, for gun cleanliness, x_3, and for fan air, x_5, dummy variables were introduced. For gun cleanliness, dummy variables take on the following values:

Level	Gun cleanliness x_3d_1	x_3d_2	x_3d_3	x_3d_4	Gun condition
a	0	0	0	1	See Figure 1
+1	0	0	1	0	See Figure 1
0	0	0	0	0	See Figure 1
-1	0	1	0	0	See Figure 1
-a	1	0	0	0	See Figure 1

Thus, for gun cleanliness at level "+1", all dummy variables except x_3d_3 take on the value of zero; x_3d_3 takes on the value of one.

In the case of fan air, dummy variables x_5d_1 and x_5d_2 take on the values shown in the table below.

Level	Fan air x_5d_1	x_5d_2	Gun setting
+1	0	1	wide open
0	0	0	one turn shut
-1	1	0	two turns shut

The analysis of variance results in a comparison of the variance associated with each experimental variable to the inherent error associated with repeat observations. This comparison is accomplished by forming the F statistic, the ratio for each value of F has a probability associated with it given the number of degrees of freedom in the numerator and in the denominator. When the probability of achieving a given value of F by chance is less than 0.05, the effect is said to be significant at the 0.05 level. The F statistics and associated probability for all factors found to be significant are presented in Table 7. (See Appendix G for a glossary of statistical terms.)

TABLE 7. AAC F-STATISTICS (F) AND ASSOCIATED PROBABILITY (P)*

Effect	Flat Panel		Vertical Cylinder		Graco	
	F	P	F	P	F	P
x_1	140.89	.0001	30.45	.0027	36.32	.0000
x_2	27.84	.033	4.49	.0376	8.57	.0022
x_3d_2	-	-	-	-	6.36	.0660
x_4	64.72	.0005	8.66	.0321	5.33	.0120
x_5d_1	163.76	.0000	16.88	.0093	53.17	.0000
x_5d_2	21.27	.0058	-	-	28.14	.0001
x_1x_2	11.59	.0192	-	-	6.01	.0800
x_4^2	32.05	.0024	-	-	7.66	.0034
$x_2x_5d_1$	10.21	.0241	-	-	-	-
$x_2x_5d_2$	22.42	.0520	-	-	9.43	.0015

*F and P are dimensionless terms. Refer to Appendix G for a definition of those terms.

In the case of all equipment types, a regression model was postulated that applied for all target types. The model considered contained linear and sometimes quadratic effects for the continuous variables and dummy variables for the quatitative variables. Certain interactions were put into the model on the basis of the best engineering experience available. All possible interactions could not be estimated due to limitation of time and resources. In all cases, the experimental design was constructed to accommodate the model terms. Terms that were significant on the basis of an F-test were retained and the final regression model is reported for each target type.

In the case of air atomized conventional, the following model terms were considered:

- linear in x_1
- quadratic in x_1
- linear in x_2
- dummy variables in x_3
- linear in x_4
- quadratic in x_4
- dummy variables in x_5
- interactions between x_1 and x_2
- interactions between x_2 and x_5

Regression models were constructed using mainframe SAS* capabilities for each of the three target types including all of those effects found to be significant at the 0.05 level. The resulting models and their associated R^2 (proportion of the overall variance explained by the regression) are presented below:

Flat Panel Target

The regression model developed for AAC FP is:

$$TE = 68.95 - 3.12x_1 - 0.98x_2 + 2.87x_4$$
$$- 1.16x_4^2 + 12.48x_5d_1 - 4.79x_5d_2 + 0.51x_1x_2$$
$$- 0.17x_2x_5d_1$$

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*Statistical Analysis System, SAS Institute, P.O. Box 10066, Raleigh,NC 27605.

The negative coefficient on x_1 indicates a tendency for TE to decrease with an increase in restricted air levels. However, there is an important interaction between the two factors as evidenced by a positive and significant coefficient of x_1x_2. While this interaction does suggest that TE continues to decrease with an increase in restricted air levels, the magnitude of that increase depends on the booth air level. The same is true for x_2, booth air. The mixed coefficients on x_4 and x_4^2 indicate that TE increases with an increase in paint line levels for the low paint line levels, but the amount of increase tapers off as the paint line levels become larger. The heavy positive coefficient on x_5d_1 suggests that TE increases when "-1" level is used on fan air. The negative coefficient on x_5d_2 suggests a decrease in TE at the "+1" level of fan air.

Since both the magnitude and direction of the effect of fan air on TE are dramatically different at different levels of fan air, the operator must be very careful to establish the appropriate fan air level for optimum TE.

The proportion of the overall variance explained by the regression (R^2) is 0.97. This R^2 indicates a tight fit of the regression model to experimental data. The standard deviation of replicate runs was 1.098, well within the targeted 2.0 standard deviation** (expressed in units of transfer efficiency).

The error in the regression model due to lack of fit was determined to be insignificant at the 0.05 level. The F-statistic for lack of fit was 1.08 (probability=0.49).

Vertical Cylinder Target

The regression model developed for AAC VC is:

$$TE = 11.99 - 0.91x_1 - 0.28x_2 + 0.44x_4 + 2.83x_5d_1$$

The F-statistics are shown in Table 7.

The negative coefficient on x_1 indicates that TE decreases with an increase in air pressure. The negative coefficient on x_2 indicates that TE decreases with an increase in booth air rates. The positive coefficient on x_4 indicates that TE increases with increasing paint pressure. The positive coefficient on fan air, only at level -1, indicates there is

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**CENTEC Corporation, "Development of Draft Standard Test Method for Spray Painting Transfer Efficiency," for USEPA under Contract 68-03-1721, Task 2.

something different about fan air at this level than at other test levels. Since fan air is a qualitative factor, it can only be speculated that certain levels of fan air affect TE more than other levels. Reducing fan air from the "0" level improved transfer efficiency, but increasing fan air did not significantly degrade TE.

The proportion of the overall variance explained by the regression (R^2) is 0.79. This R^2 is lower than for the FP target, probably due to the lack of overall variation in TE level. In the FP case, the total standard deviation for all experimental data was 9.61, while it is only 2.030 in this case. The FP target TE's were more strongly affected by experimental variations and were thus easier to model. The effect of experimental variations on VC TE's is so small that it is almost below the targeted 2.0 standard deviation for replicates. Small effects are difficult to tightly fit with regression models.

The standard deviation of VC replicates was 0.706. This low standard deviation can also be attributed to the overall insensitivity of the VC targets to experimental variables.

The error in the regression model due to lack of fit is insignificant: F = 1.53 (probability = 0.33).

Graco Target

$$\begin{aligned} TE = {} & 32.22 - 1.61x_1 - 1.24x_2 + 1.42x_3d_2 \\ & + 1.23x_4 - 0.64x_4^2 + 5.26x_5d_1 - 4.10x_5d_2 \\ & + 0.67x_1x_2 + 1.73x_2x_5d_2 \end{aligned}$$

The negative coefficient on x_1 indicates that TE decreases with an increase in air pressure (restricted lines). The negative coefficient on x_2 indicates a similar decrease in TE with increasing booth air rates. Once again, the positive coefficient on the interaction between x_1 and x_2 indicates that these trends are not constant but rather depend on the level of the interacting variable. For example, the negative trend of TE with respect to air pressure is not as pronounced when booth air rate is high, according to the regression equation. The positive coefficient on x_3 (only at level d_2) indicates that TE is affected for one level of gun cleanliness. The effect of gun cleanliness on TE at other experimental levels is insignificant.

Again, the positive coefficient on x_4 and negative sign on the quadratic term suggests a nonlinear effect of paint pressure. There is a positive slope on paint pressure until one goes beyond the x_4=1.0 level, roughly. At that point, the effect becomes negative.

The strongly positive coefficient on x_5 at the d_1 level contrasts dramatically with the strongly negative coefficient at the d_2 level. This indicates that fan air can substantially increase or decrease TE. Again, very careful selection of fan air levels is warranted by these results.

Finally, two interactions are noted: restricted air lines and booth air rate interact to affect TE, and booth air rate interacts with fan air (only at the d_2 level) to affect TE.

The proportion of the overall variance explained by the regression (R^2) is 0.97. The standard deviation of replicates is 1.261, well below the target value. The error due to lack of fit is insignificant: F = 0.82 (P = 0.773).

Tables 8, 9, and 10 present a comparison of predicted values, based on the derived regression, with observed values for the flat panel, vertical cylinder, and Graco targets respectively. The residual is the difference between predicted and observed values. The 95 percent confidence limits for the mean give the upper and lower bounds of the range within which the mean of transfer efficiency (the "true regression") at each experimental condition lies with 95 percent confidence.

AAC TEST CONCLUSIONS

The regressions previously presented illustrate the differences that target configuration can make in TE. Even with these differences, however, there are basic consistencies between the results. Three factors (restricted atomizing air lines, restricted paint lines, and fan air) were identified as significant for all tested target configurations. A fourth variable, booth air, was significant for FP and Graco targets and very nearly significant for VC targets as well. The consistency of these results strongly implies that these four factors have a critical influence on TE regardless of target configuration.

Thus, selection and maintenance of appropriate atomizing air pressure and paint pressure should be given regular attention by the operator. Fan air rates have a strongest influence on TE across all target types, as demonstrated by highly significant F-value and the large coefficient in each of the AAC regressions. Fan air levels are often set by individual operators according to their own judgment. For optimum TE, plant management should determine optimum spray painting conditions through test runs and then specify those conditions for the operator.

Some reevaluation of booth air rates may be justified by the test results, which indicate that the lowest level of booth air rate should be selected to maximize TE. Care should be taken to adhere to all safety and environmental regulations,

TABLE 8. AAC-FP COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	62.50	64.69	-2.19	62.47	66.92
2	85.90	87.87	-1.97	85.48	90.27
3	83.80	82.13	1.66	79.73	84.52
4	77.10	78.81	-1.71	76.54	81.07
5	73.80	74.87	-1.07	72.47	77.26
6	75.80	73.57	2.22	71.20	75.94
7	77.80	79.32	-1.52	77.16	81.47
8	57.40	56.47	0.92	54.51	58.44
9	82.00	80.61	1.38	78.22	83.01
10	58.20	57.43	0.76	55.20	59.65
11	60.00	63.17	-3.17	60.93	65.42
12	85.30	84.55	0.74	82.13	86.98
13	61.00	61.71	-0.71	59.35	64.08
14	68.70	67.46	1.23	65.09	69.82
15	70.70	70.44	0.25	68.19	72.68
16	65.00	62.22	2.77	60.75	63.69
17	78.10	77.15	0.94	74.25	80.05
18	63.50	62.62	0.87	59.72	65.52
19	66.70	67.92	-1.22	65.64	70.20
20	64.80	67.92	-3.12	65.64	70.20
21	59.50	59.49	0.00	56.30	62.67
22	73.50	70.98	2.51	68.22	73.73
23	80.50	80.23	0.26	78.33	82.12
24	65.70	63.13	2.56	61.44	64.82
25	58.30	58.98	-0.68	57.42	60.55
26	59.10	58.98	0.11	57.42	60.55
27	58.40	58.98	-0.58	57.42	60.55
28	58.20	58.98	-0.78	57.42	60.55
29	60.40	58.98	1.41	57.42	60.55
30	57.10	58.98	-1.88	57.42	60.55

TABLE 9. AAC-VC COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	11.90	12.73	-0.83	11.93	13.53
2	15.20	16.44	-1.24	15.44	17.45
3	16.50	15.56	0.93	14.72	16.40
4	14.60	15.01	-0.41	14.09	15.92
5	13.70	13.74	-0.04	12.74	14.75
6	13.00	13.19	-0.19	12.22	14.16
7	12.30	14.07	-1.77	13.25	14.88
8	11.00	10.35	0.64	9.50	11.21
9	15.70	14.62	1.07	13.65	15.59
10	10.70	10.91	-0.21	10.03	11.79
11	9.60	11.79	-2.19	11.06	12.52
12	16.40	15.89	0.50	14.92	16.86
13	10.70	12.17	-1.47	11.28	13.07
14	13.60	13.05	0.54	12.20	13.91
15	13.50	13.61	-0.11	12.73	14.49
16	12.60	11.23	1.36	10.70	11.77
17	15.10	14.08	1.01	13.08	15.07
18	11.70	10.44	1.25	9.50	11.38
19	12.20	11.70	0.49	11.08	12.33
20	11.50	11.70	-0.20	11.08	12.33
21	11.20	11.38	-0.18	10.38	12.37
22	13.70	13.14	0.55	12.20	14.08
23	15.70	14.54	1.15	13.77	15.32
24	11.70	11.70	-0.00	11.08	12.33
25	10.30	10.76	-0.46	10.05	11.48
26	11.20	10.76	0.43	10.05	11.48
27	9.50	10.76	-1.26	10.05	11.48
28	11.20	10.76	0.53	10.05	11.48
29	11.30	10.76	0.53	10.05	11.48
30	10.50	10.76	-0.26	10.05	11.48

TABLE 10. AAC-GRACO COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	27.40	28.03	−0.63	26.39	29.67
2	39.90	41.58	−1.68	40.05	43.11
2	41.70	40.55	1.14	39.04	42.06
4	36.80	35.32	0.97	33.78	36.86
5	33.20	34.57	−1.37	33.05	36.10
6	34.60	34.86	−0.26	33.24	36.47
7	38.50	35.89	2.60	34.60	37.18
8	25.80	25.81	−0.01	24.45	27.17
9	38.20	38.45	−0.25	36.89	40.02
10	25.00	24.90	0.09	23.29	26.52
11	26.10	25.94	0.15	24.32	27.55
12	38.40	39.20	−0.80	37.57	40.82
13	29.00	29.11	−0.11	27.43	30.79
14	31.40	30.14	1.25	28.53	31.76
15	32.40	31.91	0.38	30.27	33.55
16	29.50	29.68	−0.18	28.30	31.07
17	38.90	38.01	0.88	36.13	39.88
18	30.10	28.91	1.18	27.03	30.78
19	30.80	30.98	−0.68	29.56	32.41
20	29.50	30.98	−1.48	29.56	32.41
21	28.70	28.44	0.25	26.43	30.45
22	33.20	33.35	−0.15	31.63	35.08
23	35.90	36.24	−0.34	35.06	37.43
24	28.10	28.61	−0.51	27.32	29.91
25	25.10	26.63	−1.53	25.64	27.62
26	26.20	26.63	−0.43	25.64	27.62
27	26.20	26.63	−0.43	25.64	27.62
28	27.90	26.63	1.26	25.64	27.62
29	28.30	26.63	1.66	25.64	27.62
30	25.70	26.63	−0.93	25.64	27.62

as well as providing for worker comfort when considering lowering booth air rates. The regressions in the previous section can be used to make reasonable estimates of potential savings. These savings should be weighed against all costs before a change is made.

The Graco and FP target configurations also identified interactions between booth air rate and other variables. These interactions, while statistically significant, are not considered large enough to warrant direct practical attention. It is recommended that the plant management emphasize selection and maintenance of optimum levels for more critical variables.

The Graco target configuration identified one level of gun cleanliness as significantly affecting TE. Since this finding is not consistent across target types and is relatively small when it does appear, it is not considered critical to optimizing TE. This is not to say that gun cleanliness is unimportant to the spray painter. Gun cleanliness is one of the few O&M factors universally stressed by gun manufacturers, spray painters, and other early participants in the test program. Gun cleanliness has a profound effect on paint finish, gun life, and internal gun condition, which were not tested in this program. Only the aspect of gun cleanliness tested during this experiment is considered unimportant for AAC spray equipment.

SECTION 5

AIR ATOMIZED ELECTROSTATIC SPRAY EQUIPMENT

EQUIPMENT DESCRIPTION

A Graco Model AS-4000 manual electrostatic air spray gun was was selected for AAE testing. The Model AS-4000 gun was considered typical of an external-mix, manual electrostatic spray gun. The spray gun was equipped with a 177033 air cap, 176976 fluid tip, and a 215864 needle. Paint flow was manually initiated by opening a valve on the paint supply line. The spray gun was fixed in open position.

Graco standard black enamel was selected as the test paint. The paint averaged about 28.7 weight percent solids when cut to 30.4 seconds (#2 Shell cup at 25°C) for AAE testing. Paint was mixed in a 20 L (5 gal) paint pressure pot which was kept in a temperature-controlled booth. The paint was kept in a constant temperature booth along with the agitator, viscosity measurement equipment, and some supply lines. All paint supply lines were insulated.

AAE tests were conducted in the Dynaprecipitator water wash booth described in Section 4. Booth characteristics were identical to earlier test runs, with only two air speeds available.

Foil weights were determined on Precisa laboratory scales accurate to 0.01 g. Weight-percent-solids samples were weighed on 0.0001 g accuracy scales.

A forced-air gas-fired oven was used for curing weight-percent-solids samples and TE samples. The oven was cleaned daily to prevent contaminants from adhering to the samples. All samples were cured at 148.9°C (300°F) for 20 minutes. This is the manufacturer's recommended cure schedule for this paint.

The mass flow meter described in Section 3 was used for paint mass flow determinations during AAE testing. The test method presented in Appendix A was strictly adhered to for AAE testing, as were the QA/QC requirements of the test.

A summary of all AAE test equipment specifications is presented in Appendix D.

OPERATING AND MAINTENANCE VARIABLES

As listed in Table 11, 19 variables were identified through interviews and literature that may have potential to exert an important effect in achieving optimum TE. Seven of the identified variables were selected for AAE testing on the basis of: (1) the number of times the variable was identified for AAE by different sources, (2) the ability to simulate the variable within the prescribed test methodology, and (3) the limitation of laboratory time. This prior knowledge enabled us to limit the scope of TE experiments to only variables of particular interest.

The selected test variables were:

- Restricted atomizing air lines
- Booth air rate (linear velocity)
- Gun cleanliness
- Restricted paint lines
- Fan air (sometimes called horn air or shaping air)
- Tip voltage
- Electrode position

Restricted atomizing air lines can be simulated by decreasing the pressure of the air supply to the spray gun. An air regulator was used for reducing the air pressure to desired levels. Restricted paint lines were simulated by decreasing the paint supply pressure in a similar manner.

Booth air rate (linear velocity) was available at only two levels at this facility, 0.36 m/s and 0.61 m/s (70 ft/min and 120 ft/min) respectively. Gun cleanliness was simulated by blocking certain air holes in the air cap in a progressively worse pattern as shown in Figure 2. Fan air was adjusted by using the adjustment knob on the spray gun, while voltage supplied to the tip was adjusted at the power supply. Electrode position was set manually as shown in Figure 3.

EXPERIMENTAL DESIGN

An experimental design was developed to accommodate the limitations of testing while addressing the effects of each variable as completely as possible.

The first restraint on experimental design as noted previously was the availability of laboratory time: only

TABLE 11. OPERATING AND MAINTENANCE VARIABLES FOR AAE SPRAY EQUIPMENT*

Atomizing air

Booth air rate

Booth configuration

Conveyor speed

Cure schedule (time, temperature)

Electrode position

Equipment design

Flash off

Gun cleanliness

Gun condition

Gun-to-target distance

Operator error

Paint discharge technique

Paint mass flow rate

Paint characteristics

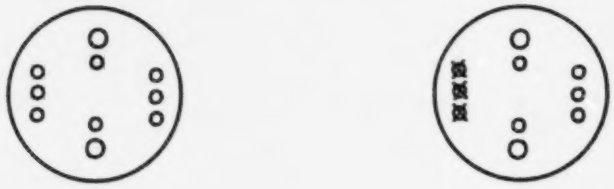
Restricted air supply

Restricted paint supply

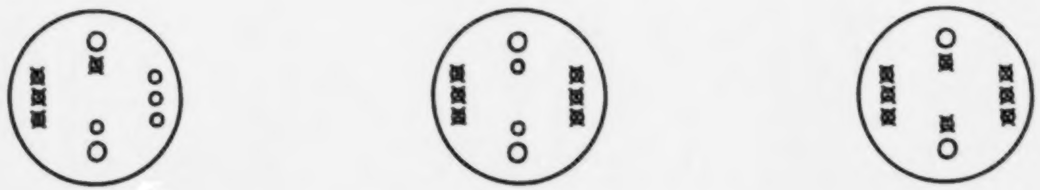
Shaping air (fan air)

Target configuration

*as mentioned by industry sources contacted

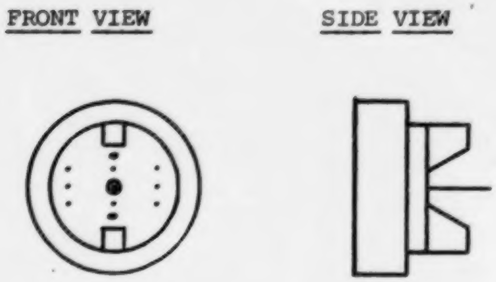


Level +a: all holes open   Level +1: 3 holes plugged

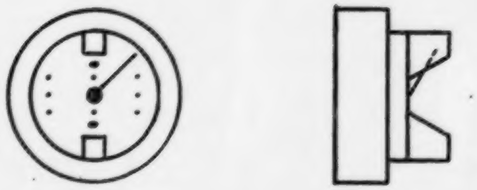


Level 0: 4 holes plugged   Level -1: 6 holes plugged   Level -a: 8 holes plugged

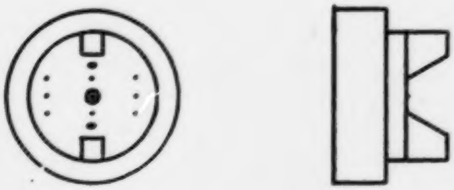
Figure 2. Air atomized electrostatic air cap (frontal view) showing selection of test levels for gun cleanliness


FRONT VIEW
SIDE VIEW

LEVEL 1



LEVEL 0



LEVEL -1

Figure 3. Air atomized electrostatic electrode position test levels

about 30 test runs could reasonably be completed during a week of testing. The second limitation was the number and type of simulation levels for each variable.

Table 12 presents the type of variable (quantitative/qualitative) and levels to be accommodated in the AAE experimental design.

A variation of a central composite experimental design was selected as the most thorough way to examine the effects of these factors with the fewest number of test runs and still allow for a regression model to be constructed. The experimental design is characterized by combining a fractional factorial design portion with a "star" portion, augmented by replicates. A slight variation central composite experimental design was constructed for factors A, C, D, E, F, and G. Five levels were required for factors A, C, D, and F but only three levels for factors E and G. Thus the design levels for the star points could not be the same for all variables. In addition, as in the AAC, the replicates were not at the traditional center of the design. For pragmatic reasons the replicates were taken at the extremes in each variable.

Table 13 presents the AAE experimental design. In this table, the abbreviations "a," "1," "0," "-1," and "-a" denote the level of each factor to be tested. Level "a" denotes the base level with a good spray pattern. Level "a" is likely to be different for each factor in each experiment. It remains constant for a given factor in a given experiment. Level "-a" denotes the poorest level of a factor to be tested. The intermediate levels "1," "0," and "-1" are determined along equal spacing from "a" to "-a" for the particular factor. Factor levels for AAE testing were determined in pretest trials as described in the following subsection.

The first 16 test runs in the experimental design are the fractional factorial portion of the design. When the effects of several factors are to be studied, a factorial design is usually the most efficient method to use.* The basic idea of factorial design is to alter several aspects of a test at a time, but in such a way that the effects of individual alterations can be determined. Fractional factorial designs sacrifice some ability to test for interaction between factors but are able to test for main effects very efficiently.

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*Youden, W. J. and Steiner, E. H., Statistical Manual of the Association of Official Analytical Chemists, Arlington, Va., 1982; and Davies, O. L., Design and Analysis of Industrial Experiments, Great Britain, 1979.

TABLE 12. OPERATING AND MAINTENANCE VARIABLES FOR AAE SPRAY PAINTING EQUIPMENT

	Variable	Quant/ qual.	No. of levels
A.	Restricted atomizing air lines	Quant.	5
B.	Booth air rate (linear velocity)	Quant.	2
C.	Gun cleanliness	Qual.	5
D.	Restricted paint lines	Quant.	5
E.	Fan air (shaping air or horn air)	Qual.	3
F.	Voltage	Quant.	5
G.	Electrode position	Qual.	3

TABLE 13. AAE EXPERIMENTAL DESIGN

	Variable						
Run number	A	B	C	D	E	F	G
1	-1	-1	-1	-1	-1	-1	-1
2	1	1	1	-1	-1	-1	1
3	-1	-1	-1	1	1	1	-1
4	1	1	1	1	1	1	1
5	1	-1	-1	1	1	-1	1
6	-1	1	1	1	1	-1	-1
7	1	-1	-1	-1	-1	1	1
8	-1	1	1	-1	-1	1	-1
9	-1	-1	1	-1	1	-1	1
10	1	1	-1	-1	1	-1	-1
11	-1	-1	1	1	-1	1	1
12	1	1	-1	1	-1	1	-1
13	1	-1	1	1	-1	-1	-1
14	-1	1	-1	1	-1	-1	1
15	1	-1	1	-1	1	1	-1
16	-1	1	-1	-1	1	1	1
17	-a	-1	0	0	0	0	0
18	a	-1	0	0	0	0	0
19	0	1	a	0	0	0	0
20	0	1	-a	0	0	0	0
21	0	-1	0	-a	0	0	0
22	0	-1	0	a	0	0	0
23	0	1	0	0	-1	0	0
24	0	1	0	0	1	0	0
25	0	-1	0	0	0	-a	0
26	0	-1	0	0	0	a	0
27	0	1	0	0	0	0	-1
28	0	1	0	0	0	0	1
29	a	1	a	a	1	a	1
30	a	1	a	a	1	a	1
31	a	1	a	a	1	a	1
32	a	1	a	a	1	a	1
33	a	1	a	a	1	a	1
34	a	1	a	a	1	a	1

Where:

A = Restricted air lines--test at 5 levels: a,1,0,-1,-a
B = Booth air rates--test at 2 levels: 1,-1
C = Gun cleanliness--test at 5 levels: a,1,0,-1,-a
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
E = Fan air--test at 3 levels: 1,0,-1
F = Voltage--test at 5 levels: a,1,0,-1,-a
G = Electrode position--test at 3 levels: 1,0,-1

Runs 17 through 28 in Table 13, are the "star" portion of the experimental design. This portion of the experiment tests the effects of variables at the extremes of their range (for the system under test, at "-a" and "a"). The star design broadens the range of information gathered in the test. The star portion of the design allows extra degrees of freedom in order to assess lack of fit.

The final six runs of the experimental design are replicates. Replicates are provided at the base condition of all variables to provide a measure of the precision of the test.

AAE TEST PERFORMANCE

AAE testing was conducted from February 13 to February 17, 1984. Spray equipment was set up on February 13 and initial spray pattern was checked. Some difficulty was encountered in establishing a good spray pattern for base levels. The fluid tip and valve seats were replaced in the spray gun, and the spray pattern improved. Base levels ("a") for each variable were established as described in the Test Method (Appendix A).

Deteriorated levels ("-a") were determined by setting all factors except one at the base level, then decreasing the level of the selected variable until a noticeably worse spray pattern resulted. Deteriorated levels of each variable were determined in turn. Intermediate levels were calculated evenly between "a" and "-a" for each quantative variable. The final selection of test levels is presented in Table 14.

Deteriorated gun cleanliness levels were determined by progressively plugging more holes in the air cap. Final gun cleanliness levels are shown in Figure 2.

Electrode position was selected through trial and error spray pattern checks after alterations in electrode position were made. Selected electrode positions for AAE TE testing are illustrated in Figure 3.

The experimental design in Table 13 was followed. Three blocks of runs were made; all of the runs in a block were of the same electrode position. Total randomization could not be accommodated without introducing an unacceptable error in trying to duplicate the desired electrode position. Pretest trials demonstrated the inability to assure consistent levels of electrode position in a totally random experiment. (Spray gun design caused straightening of the electrode whenever air cap changes were made.)

TE testing began February 14 after all documentation and QA/QC measures were completed. Six tests runs were completed. On the second day of testing 17 runs were completed, with

TABLE 14. LEVELS OF OPERATING AND MAINTENANCE VARIABLES TESTED ON AAE SPRAY PAINTING EQUIPMENT

Variable	Test levels
A. Restricted atomizing air lines*	a= 293kPa (20 psig)
	1= 218.6kPa (17 psig)
	0= 197.9kPa (14 psig)
	-1= 177.2kPa (11 psig)
	-a= 156.6kPa (8 psig)
B. Booth air rate + (linear velocity)	1= 0.61m/s (120 ft/min)
	-1= 0.36m/s (70 ft/min)
C. Gun cleanliness †	See Figure 2
D. Restricted paint lines z	a= 180.7kPa (15.5 psig)
	1= 170.3kPa (13.5 psig)
	0= 160.0kPa (11.5 psig)
	-1= 149.7kPa (9.5 psig)
	-a= 139.3kPa (7.5 psig)
E. Fan air #	1= wide open
	0= 1 turn shut
	-1= 2 turns shut
F. Voltage **	a= 72 kV
	1= 63 kV
	0= 54 kV
	-1= 45 kV
	-a= 36 kV
G. Electrode position (See Figure 3)	1= normal
	0= bent ††
	-1= clipped off

---

*Measured at the spray gun.

+Actual booth air rates varied from 100 to 140 fpm for level "+1" and 50 to 90 fpm for level "-1". Average air velocities are used in this table.

†Deteriorating gun cleaniness was simulated by blocking air cap holes as shown in Figure 2.

zMeasured at control panel approximately 20 feet from spray gun.

#Fan air (sometimes called horn air or shaping air) was adjusted by setting the control knob on the gun wide open, then turning it the required number of turns towards the closed position.

**Monitored at power supply.

††Bent down and to the left.

the remainder finished on February 16, 1984. All data were gathered according to the requirements of the Test Procedure (Appendix A) and QA/QC plan (Appendix B).

All data satisfied the requirements of the outlier analysis; no TE test runs had to be repeated.

TEST RESULTS

TE's were calculated according to the test plan. Final results are presented in Table 15. Some corrections were made to the original TE data when a QA scan identified several unusual foil weights. These foils were reweighed and the correct weights used to recalculate TE values. These corrections are reflected in Table 15.

STATISTICAL ANALYSIS

Regressions are described for each target type in the same manner as described previously for air atomized conventional equipment. A discussion of how to use the regression equations is included in the AAC Statistical Analysis section.

For AAE equipment, the variables are designated as follows:

x_1=restricted atomizing air lines

x_2=booth air rate (linear velocity)

x_3=gun cleanliness

x_4=restricted paint lines

x_5=fan air (shaping air or horn air)

x_6=voltage

x_7=electrode position

TE=transfer efficiency

Factors x_3,x_5 and x_7 are qualitative variables and therefore have dummy variables associated with them. The regressions developed for each target type follows.

In the case of air atomized electrostatic spray equipment, engineering judgment suggested that the following model terms, including interactions, should be considered.

- Linear and quadratic in x_1
- Linear in x_2

TABLE 15. AAE TEST RESULTS

	TE result		
Run number	FP	VC	Graco
1	93.3	33.8	56.2
2	90.2	37.1	60.2
3	92.4	45.3	60.2
4	96.2	61.1	72.2
5	92.2	48.5	62.8
6	93.1	28.1	49.5
7	93.1	67.3	77.7
8	94.3	40.9	57.6
9	96.5	60.5	70.1
10	87.4	34.6	54.4
11	98.8	63.3	72.8
12	96.2	29.8	57.3
13	91.7	30.5	52.6
14	96.7	41.7	62.3
15	89.6	49.8	61.5
16	98.8	70.4	78.7
17	102.0	50.4	67.4
18	88.4	42.0	60.8
19	94.4	47.4	67.9
20	93.0	45.0	64.0
21	88.4	44.5	65.5
22	100.0	56.5	70.5
23	96.5	31.9	56.7
24	93.0	29.6	56.7
25	90.5	28.6	54.9
26	96.0	44.8	70.0
27	87.0	36.3	54.0
28	94.9	52.7	69.1
29	96.7	76.4	78.1
30	86.8	77.8	78.6
31	92.9	79.6	77.7
32	94.0	75.4	75.0
33	98.6	79.8	77.9
34	95.4	73.9	80.8

- Dummy variables in x_3
- Linear and quadratic in x_4
- Dummy variables in x_5
- Linear and quadratic in x_6
- Dummy variables in x_7
- Interaction between x_2 and x_5

Flat Panel Target

$$TE = 94.72 - 2.27x_1 + 1.56x_4 + 1.22x_6 - 3.05x_7d_1$$

All factors are significant only in linear form. No quadratic factors are significant for this gun type and target configuration. The negative coefficient on x_1 indicates a drop in TE as air pressure increases. The positive coefficient on x_4 suggests that TE increases with increasing paint pressure. Likewise, the positive coefficient on x_6 indicates that TE increases with increased voltage. The negative coefficient on x_7d_1 suggests a significant drop in TE, but only when the electrode position is at level "-1." (See Figure 3 to visualize level "-1" compared to the other electrode positions.)

The proportion of overall variance explained by the regression (R^2) is 0.67. This is a low R^2. It is the result of a lack of overall variance among test runs for this target configuration. The overall variance of all of the TE determinations for AAE FP was 3.69, only about one and a half TE unit above the targeted precision of 2.0. When the overall variance is low, it is difficult to tightly fit a regression model to account for the small differences from run to run.

The standard deviation of the replicates was 2.070, higher than for most other cases, but very near the target value of 2.0.*

The error in the regression due to lack of fit was insignificant with F = 1.42 (0.37 probability).

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*CENTEC Corporation, "Development of Draft Standard Test Method for Spray Painting Transfer Efficiency," for USEPA under Contract No. 68-03-1721, Task 2.

Vertical Cylinder Target

The derived regression equation for AAE VC is:

$$\begin{aligned} TE = {} & 41.34 - 1.11x_1 - 2.66x_2 - 2.33x_3d_3 \\ & + 2.46x_4^2 - 8.20x_5d_1 + 6.71x_6 - 0.99x_6^2 \\ & + 18.25x_7d_2 + 1.82x_2x_5 \end{aligned}$$

In this case, several factors are significant, in both linear and quadratic form. As in the flat panel case, the negative coefficient on x_1 indicates that as air pressure increases, TE drops. Similarly, the negative coefficient on x_2 indicates that as booth air rate increases TE decreases. This negative effect is moderated by the interaction of booth air with x_5, fan air. The positive coefficient of x_2x_5 indicates that the rate of change of TE with respect to booth air depends on the prevailing level of fan air. In particular, this slope becomes positive when the fan air is at the "wide open" level. Gun cleanliness, x_3, exerts a significant effect on TE only at the "+1" level. (Figure 2 illustrates the different levels of gun cleanliness.) Restricted paint lines are quadratically significant with a positive coefficient, indicating that an increase in paint pressure also increases TE.

This may suggest that there are interactions or special effects on TE at certain levels of fan air for this system. The positive linear coefficient on voltage indicates that as voltage increases, TE increases. The negative quadratic coefficient on voltage indicates a nonlinear effect for voltage increases. This negative coefficient moderates the positive trend for the higher levels of voltage. Electrode position was found to be significant only at position "+1" (shown in Figure 3), but not for other electrode positions.

The proportion of overall variance explained by the regression (R^2) is 0.92. This is a relatively high R^2, and considered indicative of a good fit of the regression.

The standard deviation of replicate runs was 2.356, just over the target standard deviation of 2.0 for the procedure.

The error due to lack of fit was statistically insignificant at the 5 percent significance level (F = 2.66).

Graco Target

The derived regression for AAE testing using Graco targets is:

$$\begin{aligned} TE = {} & 66.78 - 0.89x_1 - 1.14x_2 - 4.35x_3d_3 \\ & - 0.67x_4 + 1.12x_4^2 - 5.62x_5d_1 - 4.18x_5d_2 \\ & + 4.20x_6 - 6.88x_7d_1 + 6.76x_7d_2 \end{aligned}$$

The directional effects of x_1, x_2, x_3 (at "+1" level), x_5 (at "-1" level), and x_6 are the same as for the vertical cylinder AAE case. Three new effects are identified for Graco targets as compared to VC targets, as follows:

- Restricted paint lines have a small negative linear effect.
- Fan air is found significant at both the "-1" and "+1" levels. Both levels produce poorer transfer efficiency compared to the "0" level.
- Electrode position is found to have a significant effect at d_1 (level "-1") and at d_2 (level "+1").

The proportion of overall variance explained by the regression (R^2) is 0.94. This is considered a high value, indicative of the good fit of the regression. The standard deviation of replicate Graco test runs was 1.8606, well within the 2.0 limitation set by the test procedure.

Table 16 presents the values of F and the associated probability (P) for all variables and interactions found to be significant.

Tables 17, 18, and 19 present a comparison of predicted values with observed for the flat panel, vertical cylinder, and Graco target respectively.

AAE CONCLUSIONS

These regressions illustrate the differences target configuration can make in TE. Even with these differences, however, there are fundamental consistencies among the results. Four variables (restricted air lines, restricted paint lines, voltage, and electrode position) are significant for all target types. Three other variables (booth air rate, gun cleanliness, and fan air) are significant for VC and Graco target configurations. The consistency of these results across target types strongly implies that all of the factors tested for AAE spray equipment have an important impact on TE.

The relative importance of each variable for a certain target configuration should be given individual consideration by plant management. It is recommended that laboratory test runs be made with plant paint and workpiece targets to determine optimum combinations of factor levels that result in acceptable product finish. The developed regressions should serve as guidelines in setting up the experimental design for site-specific TE testing. If such tests are impractical, the regressions may serve as guidelines toward maximizing TE. Care must be taken when extrapolating the results for one spray system to another. Previous test experience indicates that paint characteristics, spray system characteristics, and target geometry can significantly alter TE test results; however, the regressions may be considered directionally sound for similar spray systems.

TABLE 16. AAE F-STATISTICS (F) AND ASSOCIATED PROBABILITY (P)*

	Flat Panel		Vertical Cylinder		Graco	
Effect	F	P	F	P	F	P
x_1	22.08	.0053	13.84	.0137	5.71	.0038
x_2	-	-	34.58	.0020	9.73	.0003
x_3d_3	-	-	11.28	.020	13.85	
x_4	13.52	.0143	-	-	3.29	.0333
x_5d_1	-	-	16.31	.0099	11.93	.0000
x_5d_2	-	-			6.71	.0018
x_6	3.34	.0342	159.6	.0000	122.94	.0000
x_7d_1	13.18	.065	-	-	18.77	.0001
x_7d_2	-	-	92.1	.0002	28.99	.0000
x_4^2	-	-	18.62	.0076	10.61	.0002
x_6^2	-	-	12.15	.0175	-	-
x_2x_5	-	-	7.68	.039	-	-

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* F and P are dimensionless. Refer to Appendix G for a definition of these terms.

TABLE 17. AAC-FP COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	93.30	91.15	2.14	89.40	92.90
2	90.20	89.66	0.53	87.76	91.57
3	92.40	96.71	-4.31	94.55	98.86
4	96.20	95.22	0.97	94.20	96.24
5	92.20	92.78	-0.58	91.01	94.54
6	93.10	94.26	-1.16	92.11	96.42
7	93.10	92.11	0.98	90.34	93.87
8	94.30	93.60	0.69	91.44	95.75
9	96.50	94.20	2.29	92.61	95.80
10	87.40	86.61	0.78	84.46	88.77
11	98.80	99.76	-0.96	97.99	101.52
12	96.20	92.17	4.02	90.42	93.92
13	91.70	89.73	1.96	87.57	91.88
14	96.70	97.31	-0.61	95.41	99.22
15	89.60	89.06	0.53	86.90	91.21
16	98.80	96.65	2.14	94.75	98.55
17	102.00	99.25	2.74	97.22	101.28
18	88.40	90.17	-1.77	88.40	91.94
19	94.40	94.71	-0.31	93.71	95.71
20	93.00	94.71	-1.71	93.71	95.71
21	88.40	91.60	-3.20	89.57	93.63
22	100.00	97.82	2.17	96.05	99.59
23	96.50	94.71	1.78	93.71	95.71
24	93.00	94.71	-1.71	93.71	95.71
25	90.50	92.27	-1.77	90.24	94.30
26	96.00	97.16	-1.16	95.39	98.92
27	87.00	91.66	-4.66	90.15	93.17
28	94.90	94.71	0.18	93.71	95.71
29	96.70	95.73	0.96	94.10	97.35
30	96.80	95.73	1.06	94.10	97.35
31	92.90	95.73	-2.83	94.10	97.35
32	94.00	95.73	-1.73	94.10	97.35
33	98.60	95.73	2.86	94.10	97.35
34	95.40	95.73	-0.33	94.10	97.35

TABLE 18. AAC-VC COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	33.80	33.49	0.30	27.12	39.86
2	37.10	40.57	-3.47	34.27	46.87
3	45.30	51.46	-6.16	45.20	57.72
4	61.10	65.82	-4.72	60.99	70.65
5	48.50	54.08	-5.58	47.38	60.78
6	28.10	36.38	-8.28	30.24	42.52
7	67.30	62.94	4.35	56.20	69.67
8	40.90	37.96	2.93	31.56	44.35
9	60.50	56.30	4.19	49.76	62.83
10	34.60	34.16	0.43	28.36	39.96
11	63.80	65.16	-1.86	58.31	72.00
12	29.80	35.74	-5.94	29.62	41.86
13	30.50	31.27	-0.77	24.60	37.95
14	41.70	42.79	-1.09	36.34	49.24
15	49.80	49.24	0.55	42.93	55.56
16	70.40	68.04	2.35	62.31	73.77
17	50.40	43.88	6.51	38.37	49.39
18	42.00	39.44	2.55	32.53	46.36
19	47.40	38.68	8.71	33.85	43.50
20	45.00	38.68	6.31	33.85	43.50
21	44.50	51.52	-7.02	44.22	58.82
22	56.50	51.52	4.97	44.22	58.82
23	31.90	26.34	5.55	19.89	32.78
24	29.60	38.17	-8.57	32.80	43.54
25	28.60	24.30	4.29	15.39	33.22
26	44.80	51.13	-0.05	31.73	40.97
27	36.30	36.35	-0.05	31.73	40.97
28	52.70	54.60	-1.90	48.17	61.03
29	76.40	75.86	0.53	71.47	80.24
30	77.80	75.86	1.93	71.47	80.24
31	79.60	75.86	3.73	71.47	80.24
32	75.40	75.86	-0.46	71.47	80.24
33	79.80	75.86	3.93	71.47	80.24
34	73.90	75.86	-1.96	71.47	80.24

TABLE 19. AAC-GRACO COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	56.20	53.89	2.30	51.25	56.53
2	60.20	63.49	-3.29	60.43	66.54
3	60.20	62.38	-2.18	59.26	65.51
4	72.20	71.98	0.21	69.97	73.99
5	62.80	65.87	-3.07	62.85	68.90
6	49.50	51.71	-2.21	48.65	54.76
7	77.70	74.16	3.53	71.03	77.29
8	57.60	60.00	-2.40	56.94	63.05
9	70.10	68.99	1.10	65.92	72.06
10	54.40	51.27	3.12	48.22	54.33
11	72.80	74.59	-1.79	71.47	77.72
12	57.30	56.88	0.41	54.10	59.66
13	52.60	50.77	1.82	47.63	53.91
14	62.30	63.92	-1.62	60.86	66.97
15	61.50	61.95	-0.45	58.82	65.08
16	78.70	75.10	3.59	72.13	78.06
17	67.40	65.34	2.05	62.62	68.06
18	60.80	61.79	-0.99	58.65	64.93
19	67.90	65.63	2.26	62.08	69.19
20	64.00	65.63	-1.63	62.08	69.19
21	65.50	69.37	-3.87	65.13	73.62
22	70.50	66.69	3.80	63.13	70.25
23	56.70	55.66	1.03	51.90	59.42
24	56.70	57.10	-0.40	53.33	60.87
25	54.90	55.18	-0.28	52.45	57.90
26	70.00	71.96	-1.96	68.82	75.10
27	54.00	54.40	-0.40	50.65	58.16
28	69.10	68.06	1.03	64.29	71.83
29	78.10	77.96	0.13	75.92	80.00
30	78.60	77.96	0.63	75.92	80.00
31	77.70	77.96	-0.26	75.92	80.00
32	75.00	77.96	-2.96	75.92	80.00
33	77.90	77.96	-0.06	75.92	80.00
34	80.80	77.96	2.83	75.92	80.00

SECTION 6

AIRLESS CONVENTIONAL SPRAY EQUIPMENT

EQUIPMENT DESCRIPTION

In airless spray painting, the paint flows from an orifice at high pressure and breaks up into spray as it enters the atmosphere. Typical paint line pressures are 6900 to 27600 kPa (roughly 1000 to 4000 lbs/in^2). Airless spraying avoids the problem of turbulence caused by compressed air, which sometimes prevents proper deposition of the paint on the workpiece. Airless spray guns will atomize paint and permit application into corners and recessed interior areas without the blow back experienced with air spraying.

Dirt or other small particles can obstruct the flow of paint through the small orifice, which provides the atomization in airless spray; therefore, special guns, pumps, hoses, etc., are required for airless spray. Use of airless spray eliminates the need for a hose from the compressor to the spray gun (See Figure 4).

Droplet sizes in airless spraying are larger than with compressed air atomizing and consequently coatings applied by airless spray are heavier and rougher. Airless painting is used widely to apply zinc primers and other highly pigmented paints and is especially useful for large objects.

OPERATING AND MAINTENANCE FACTORS

Airless conventional spraying is an uncomplicated process with few parameters involved. The paint is supplied at high pressure to the gun from which it is expelled through a single orifice. The orifice is designed to shape the spray. Orifices are designated by the diameter and half-width of the laydown at 25.4 cm (10 in) target distance. While plugging of one or more holes in a conventional air spray cap is an operating and maintenance problem, plugging of the single hole in an airless cap, while possible, is such an obvious situation that the spray gun operator always detects and corrects the problem before proceeding.

Erosion of the orifice with continued use does present a maintenance problem for gun operation. Obstructed paint supply

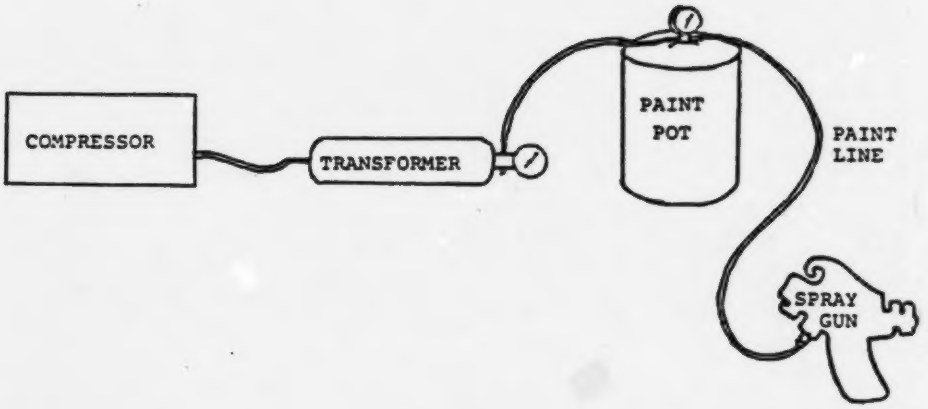
COMPRESSOR
TRANSFORMER
PAINT POT
PAINT LINE
SPRAY GUN

Figure 4. Airless paint spraying system

lines leading to reduced pressure at the gun is also a concern. Finally, the flow of air in the vicinity of the target is of interest.

Test variables selected, then, were tip erosion, line plugging, and varying booth air flow (See Table 20). The effect of these variables on the spray painting operation were respectively simulated by using orifices of progressively greater diameter, by reducing the pressure of the paint at the gun, and by reducing the booth air flow. Tip erosion was tested at three levels; unused tip with 0.28 mm (0.011 in) diameter, 0.33 mm (0.013 in) diameter, and 0.38 mm (0.015 in) diameter orifices. Restricted paint lines were tested at five levels: 9066.9 kPa (1300 lbs/in^2), 8377.2 kPa (1200 lbs/in^2), 7687 6kPa (1100 lbs/in^2), 6997.9 kPa (1000 lbs/in^2), and 6308.3 kPa (900 lbs/in^2). Booth air rate was simulated at two levels.

ALC equipment specifications for the test are included in Appendix E.

EXPERIMENTAL DESIGN

The experimental design for the airless conventional spray is shown in Table 21. It is discussed in more detail in the Subtask Report, Appendix G.

TEST PERFORMANCE

Testing was carried out during the week of February 20, 1984. The base condition was first selected using a 0.28 mm tip orifice operating at 9066.9kPa (1300 lbs/in^2) with normal exhaust air flow of 61 m/s (120 ft/min) at the plane of the target. The gun-to-target distance was selected as 40.6 cm (16 in). Because the airless spray technology produces a heavy single-coat laydown, the conveyor was kept at maximum speed to produce a good quality coating on the target with no evidence of sag. The base condition selected gave a high quality finish with no evidence of "tails;" it represented a good simulation of a production operation.

The test plan was carried out in the randomized order as shown in Table 22.

Airless spray typically requires paint of higher viscosity than does air atomized spray equipment. So although the same base paint (Graco black enamel) was used, the viscosity was increased for this series of tests. This test involved only three independent variables. In addition, a dummy variable was incorporated in the test plan to give additional information about the inherent error. With a dummy variable it was possible

TABLE 20. LEVELS OF OPERATING AND MAINTENANCE VARIABLES TESTED ON ALC SPRAY PAINTING EQUIPMENT

Factor	Quant/ qual.	No. of levels	Test levels
B. Booth air rate* (linear velocity)	Quant.	2	1= 0.61m/s (120 ft/min) -1= 0.36m/s (70 ft/min)
C. Tip erosion+	Quant.	5†	a= 0.28 mm (.011 in.) cap 1= 0.28 mm (.011 in.) cap 0= 0.33 mm (.013 in.) cap -1= 0.38 mm (.015 in.) cap -a= 0.38 mm (.015 in.) cap
D. Restricted paint lines	Quant.	5	a= 9066.9 kPa (1300 psig)z 1= 8377.2 kPa (1200 psig) 0= 7687.6 kPa (1100 psig) -1= 6997.9 kPa (1000 psig) -a= 6308.3 kPa (900 psig)
DUMMY	Qual.	3	n/a

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*Actual booth air rates varied from 100 to 140 ft/min for level "+1" and 50 to 90 ft/min for level "-1." Average air velocities are used in this table.

+Gun cleanliness was interpreted as "tip erosion" for this experiment. Progressively wider tip hole diameters were used to simulate tip wear.

†The original experimental design called for five levels; in practice we were only able to simulate three levels.

zMeasured at gun downstream of all paint filters.

TABLE 21. ALC EXPERIMENTAL DESIGN

	Variable			
Run Number	B	C	D	Dummy
1	-1	-1	-1	-1
2	1	-1	-1	-1
3	-1	1	-1	-1
4	-1	-1	1	-1
5	-1	-1	-1	1
6	1	1	-1	-1
7	1	-1	1	-1
8	1	-1	-1	1
9	-1	1	1	-1
10	-1	1	-1	1
11	-1	-1	1	1
12	1	1	1	-1
13	1	1	-1	1
14	-1	1	1	1
15	1	-1	1	1
16	1	1	1	1
17	1	-a	0	0
18	1	a	0	0
19	-1	0	-a	0
20	-1	0	a	0
21	1	0	0	-1
22	1	0	0	1
23	1	a	a	1
24	1	a	a	1
25	1	a	a	1
26	1	a	a	1
27	1	a	a	1
28	1	a	a	1

Where:

B = Booth air rates--test at 2 levels: 1,-1
C = Tip erosion at 3 levels
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
Dummy = Dummy variable not expected to affect TE

TABLE 22. ORDER OF PERFORMANCE OF ALC TEST RUNS

23
21
5
25
29
11
2
16
15
28
22
10
17
7
6
13
9
19
26
12
8
27
14
1
24
18
3
4

(28 runs)

to reduce some of the planned runs without sacrificing information. Runs 6, 11, 16, 23, 25, and 28 were dropped from the design as shown in Table 21.

In the case of airless conventional, the experimental design allowed for estimation of regression terms of the following type:

- Linear in x_1
- Linear and quadratic in x_2
- Linear and quadratic in x_3

TEST RESULTS

Tests were run and calculations performed in accordance with the standard test method. Values of transfer efficiency obtained during testing are shown in Table 23.

STATISTICAL ANALYSIS

Based on the TE test results, regression models were developed to fit the data. Information on how to use these regressions is presented in the AAC Statistical Analysis section of this report.

Variables are named in the regressions that follow according to the table below:

x_1=booth air flow

x_2=tip erosion

x_3=restricted paint lines.

TE=transfer efficiency

Only those variables found to be significant have been included in the final regression. Tip erosion, x_2, is a qualitative factor and therefore has dummy variables associated with it.

Flat Panel Target

The derived regression equation for ALC testing of flat panel targets is:

$$TE = 74.4 - 5.47x_2 - 1.94x_2^2$$

TABLE 23. ALC TEST RESULTS

Run number	Percent transfer efficiency FP	VC	Graco
1	76.6	13.0	33.7
2	76.6	13.6	33.1
3	63.1	10.4	28.4
4	79.5	13.7	33.0
5	79.2	13.8	33.6
7	77.6	12.9	33.4
8	75.9	13.2	33.0
9	68.3	11.2	26.9
10	66.0	10.4	25.9
12	69.4	10.6	27.6
13	64.8	10.8	27.5
14	66.6	10.5	27.5
15	80.5	14.8	35.0
17	77.5	13.2	34.1
18	65.5	10.8	26.7
19	75.7	12.7	32.2
20	74.8	13.1	34.5
21	76.4	13.3	32.4
22	70.7	12.5	34.4
24	67.7	10.6	27.3
26	68.3	11.0	27.3
27	70.2	10.9	27.9

The only significant variable affecting TE is tip erosion. The negative coefficient on x_2d_2 implies that tip erosion at level "1" makes TE go down. The positive sign on x_2d_1 means that the level "-1" makes TE increase.

The proportion of overall variance explained by the regression (R^2) is 0.87. This is considered a high value, indicative of a good fit of the regression. The standard deviation of replicate FP test runs was 1.305, well within the range of 2.0 specified in the test procedure.* The error due to lack of fit was insignificant, with F = 2.16 (P = 0.36). (Refer to Appendix G for a glossary of statistical terms.)

Vertical Cylinder Target

The regression analysis derived for ALC testing of VC targets is:

$$TE = 12.90 - 1.40x_2 - 0.78x_2^2$$

Like the FP case, tip erosion was the only significant variable found to affect TE for airless conventional spray equipment. In this case the direction of the effect is similarly contingent on selection of level (i.e. d_1 or d_2).

The proportion of overall variance explained by the regression model is 0.91. This indicates a good fit of the regression.

The standard deviation of replicate VC test runs was extremely small, at only 0.208. While this standard deviation is admirable given the test procedure precision of 2.0, it raises some question as to why the procedure is so repeatable for this target configuration. The answer lies in the very small overall standard deviation (only 1.4 across the entire data set) created by intentional introduction of O&M variables. The insensitivity of this system to intentional attempts to alter TE demonstrates why the replicate standard deviation is so small.

The error due to lack of fit was insignificant at the 0.05 level, with F= 7.76 (P= 0.12).

Graco Target

The regression analysis derived for ALC testing of Graco targets is:

$$TE = 33.38 - 3.25x_2 - 2.98x_2^2 - 0.26x_3$$

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*CENTEC Corporation, "Development of Draft Standard Test Method for Spray Painting Transfer Efficiency," for USEPA under Contract 68-03-1721, Task 2.

Tip erosion is found significant only at the d_2 ("+1" level) for this target configuration. This is an overwhelmingly large effect, indicating that the effect on TE is very different at this tip diameter than at other tip diameters for this system. Restricted paint lines are also significant for this case, but only marginally so. No interaction between factors is noted for this system.

The proportion of overall variance explained by the regression (R^2) is high at 0.95. This indicates a well fitting model. The standard deviation of Graco target replicate test runs is 0.346. Like the previous ALC cases, this extremely low standard deviation is the result of the insensitivity of this system to the intentional introduction of O&M factors.

The F statistics and associated probabilities are given in Table 24 for each effect included in the regression.

TABLE 24. ALC F-STATISTICS (F) AND ASSOCIATED PROBABILITIES (P)*

	Flat Panel		Vertical Cylinder		Graco	
Effect	F	P	F	P	F	P
x_1	-	-	-	-	-	-
x_2d_1	11.39	.077	19.99	.0466	-	-
x_2d_2	89.56	0.00	255.33	.0044	383.63	.0000
x_3	-	-	-	-	16.59	.0002

Tables 25, 26, and 27 present a comparison of predicted and observed transfer efficiency values, along with associated significance limits, for the flat panel, vertical cylinder, and Graco targets, respectively.

ALC CONCLUSIONS

Three O&M variables were selected for testing on ALC spray painting equipment: tip erosion, booth air rate, and restricted paint lines. In every test case, tip erosion is the overwhelming variable affecting TE. The only other variable identified as significant in any ALC test was restricted paint lines for the Graco target.

The tremendous response to changes in tip diameter is indicative of a very strong relationship between selection of appropriate tip diameter and TE. Tip diameter should be carefully selected. Table 24 shows that the "+1" level displays by far the most significant effect for all three target types.

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*Refer to Appendix G for glossary of statistical terms.

TABLE 25. ALC-FP COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	76.60	77.92	-1.32	76.39	79.45
2	76.60	77.92	-1.32	76.39	79.45
3	63.10	66.99	-3.89	65.61	68.36
4	79.50	77.92	1.57	76.39	79.45
5	79.20	77.92	1.27	76.39	79.45
6	77.60	77.92	-0.32	76.39	79.45
7	75.90	77.92	-2.02	76.39	79.45
8	68.30	66.99	1.31	65.61	68.36
9	66.00	66.99	-0.99	65.61	68.36
10	69.40	66.99	2.41	65.61	68.36
11	64.80	66.99	-2.19	65.61	68.36
12	66.60	66.99	-0.39	65.61	68.36
13	80.50	77.92	2.57	76.39	79.45
14	77.50	77.92	-0.42	76.39	79.45
15	65.50	66.99	-1.49	65.61	68.36
16	75.70	74.40	1.30	72.23	76.56
17	74.80	74.40	0.40	72.23	76.56
18	76.40	74.40	2.00	72.23	76.56
19	70.70	74.40	-3.70	72.23	76.56
20	67.70	66.99	0.71	65.61	68.36
21	68.30	66.99	1.31	65.61	68.36
22	70.20	66.99	3.21	65.61	68.36

TABLE 26. ALC-VC COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	13.00	13.52	−0.52	13.20	13.84
2	13.60	13.52	0.07	13.20	13.84
3	10.40	10.72	−0.32	10.42	11.01
4	13.70	13.52	0.17	13.20	13.84
5	13.80	13.52	0.27	13.20	13.84
6	12.90	13.52	−0.62	13.20	13.84
7	13.20	13.52	−0.32	13.20	13.84
8	11.20	10.72	0.48	10.42	11.01
9	10.40	10.72	−0.32	10.42	11.01
10	10.60	10.72	−0.12	10.42	11.01
11	10.80	10.72	0.08	10.42	11.01
12	10.50	10.72	−0.22	10.42	11.01
13	14.80	13.52	1.27	13.20	13.84
14	13.20	13.52	−0.32	13.20	13.84
15	10.80	10.72	0.08	10.42	11.01
16	12.70	12.90	−0.20	12.44	13.35
17	13.10	12.90	0.20	12.44	13.35
18	13.30	12.90	0.40	12.44	13.35
19	12.50	12.90	−0.40	12.44	13.35
20	10.60	10.72	−0.12	10.42	11.01
21	11.00	10.72	0.28	10.42	11.01
22	10.90	10.72	0.18	10.42	11.01

TABLE 27. ALC-GRACO COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	33.70	33.38	0.31	32.77	33.99
2	33.10	33.38	-0.28	32.77	33.99
3	28.40	26.88	1.51	26.20	27.56
4	33.00	33.90	-0.90	33.25	34.55
5	33.60	33.38	0.21	32.77	33.99
6	33.40	33.90	-0.50	33.25	34.55
7	33.00	33.38	-0.38	32.77	33.99
8	26.90	27.40	0.50	26.89	27.91
9	25.90	26.88	-0.98	26.20	27.56
10	27.60	27.40	0.19	26.89	27.91
11	27.50	26.88	0.61	26.20	27.56
12	27.50	27.40	0.09	26.89	27.91
13	35.00	33.90	1.09	33.25	34.55
14	34.10	33.64	0.45	33.08	34.20
15	26.70	27.14	-0.44	26.61	27.67
16	32.20	32.85	-0.65	31.87	33.83
17	34.50	33.89	0.60	32.91	34.87
18	32.40	33.37	-0.97	32.58	34.16
19	34.40	33.37	1.02	32.58	34.16
20	27.30	27.66	-0.36	27.02	28.30
21	27.30	27.66	-0.36	27.02	28.30
22	27.90	27.66	0.23	27.02	28.30

From the data generated during this test program, very little can be said about the effects of other variables on TE for ALC spray systems. The response of TE to tip erosion is so dramatic that it may obscure other potentially important variables.

SECTION 7

AIRLESS ELECTROSTATIC SPRAY EQUIPMENT

EQUIPMENT DESCRIPTION

A Graco Model AL-4000 was selected as the ALE spray equipment for TE testing. The AL-4000 is operated like conventional airless spray equipment except the spray is electrically charged. The electrical charge is an attractive agent pulling the paint towards the nearest ground, the target. Electrical power is supplied at a controlled voltage on the electrode at the gun tip. Fluid flows through the gun at high pressure and is atomized through a carbide tip. The atomized paint picks up an electrical charge as it is sprayed past the charged electrode. The spray pattern of ALE equipment is determined primarily by tip orifice size. Fluid flow cannot be adjusted at the gun (as it can in conventional and conventional electrostatic equipment); it is either full on or full off.

Graco standard black enamel was used as the test paint. It was cut to 25.5 seconds on a Shell #3 cup at 25°C. A 16 L (4 gal) batch of paint was mixed and stored in a 20 L (5 gal) Graco paint pressure pot. This batch was not enough to complete all ALE testing and was made up on the second and third days of testing. The paint was kept in a constant temperature booth along with the paint pump (Model 207-707, K3D 30:1), stirrer, viscosity measurement equipment, and some supply lines. All paint supply lines were insulated.

ALE tests were conducted in the Dynaprecipitator water wash booth described in Section 4. Booth characteristics were identical to earlier test runs, with only two air speeds available.

Foil weights were determined on Precisa laboratory scales accurate to 0.01 g. Weight-percent-solids samples were weighed on 0.0001 g accuracy scales.

A forced-air, gas-fired oven was used for curing weight-percent-solids samples and TE samples. The oven was cleaned daily to prevent contaminants from adhering to the samples. All samples were cured at 171.1°C (340°F) for 20 minutes. This is a more severe cure than for previous experiments. It was instituted to ensure a complete cure for the heavier laydown of paint expected for this equipment type. Trial and error weight-percent solids determinations were made to document the point of assured complete curing.

The mass flow meter described in Section 3 was used for paint mass flow determinations. The test method presented in Appendix A was strictly adhered to for ALE testing, as were the QA/QC requirements of the test.

ALE equipment specifications for this test series are included in Appendix F.

OPERATING AND MAINTENANCE FACTORS

Variables had been previously identified through interviews and literature search that were considered to have an important effect in achieving optimum TE for ALE equipment. These 14 variables are presented in Table 28. Five variables were selected for ALE testing on the basis of the number of times it was identified for ALE by different sources, the ability to simulate the variable within the prescribed test methodology, and finally, the limitation of laboratory time. The five selected test variables were:

- Booth air rate (linear velocity)
- Tip erosion (substituted for gun cleanliness)
- Restricted paint lines
- Voltage
- Electrode position

A dummy variable was also included to provide a measure of the inherent error in the experiment.

EXPERIMENTAL DESIGN

An experimental design was developed to accommodate the limitations of testing while addressing the effects of each variable as completely as possible.

As before, the first restraint on experimental design was the availability of laboratory time: only about 30 test runs could be reasonably expected during a week of testing. The second limitation was the number and type of simulation levels for each variable. Only two booth air rates were possible in the test laboratory, while three levels of fan

TABLE 28. OPERATING AND MAINTENANCE VARIABLES FOR ALE SPRAY EQUIPMENT*

Booth air rate

Booth configuration

Cure schedule (time, temperature)

Paint discharge technique

Equipment design

Flash off

Gun cleanliness

Gun condition

Gun-to-target distance

Operator error

Paint mass flow rate

Paint characteristics

Restricted paint supply

Target configuration

*as mentioned by industry sources contacted air were achievable, and five or more levels of some other variable could be simulated. Table 29 presents the type of variable (quantitative/qualitative) and levels to be accommodated in the experimental design.

Table 29 shows the use of a dummy variable. This variable represents the effect of a totally unrelated action on TE. If the data analysis shows any significant effect for the dummy variable it is indicative of some type of problem with the test method or test performance.

Table 30 presents the ALE experimental design. In this figure, the abbreviations "a," "1," "0," "-1," and "-a" denote the level of each variable to be tested. Level "a" denotes the base level with a good spray pattern. Level "-a" denotes the poorest level of a factor to be tested. The intermediate levels "1," "0," and "-1" are determined along equal spacing from "a" to "-a" for the particular variable. Variable levels for ALE testing were determined in pretest trials as described in the following subsection.

The first 16 test runs in the experimental design are the fractional factorial portion of the design. When the results of several variables are to be studied, a factorial design is usually the most efficient method to use.* The basic idea of factorial design is to alter several aspects of a test at a time, but in such a way that the effects of individual alterations can be determined. Fractional factorial designs sacrifice some ability to test for interaction between variables but are able to test for main effects very efficiently.

Runs 17 through 26 in Table 30, are the "star" portion of the experimental design. This portion of the experiment tests the effects of variables at the extremes of their range (for the system under test, at "-a" and "a"). The star design broadens the range of information gathered in the test. The star portion of the design allows extra degrees of freedom in order to assess lack of fit.

As in the case of previous designs, the design used here entails a central composite design for variables C, D, F, and G. However, G contains only 3 levels while C, D, and F contain 5 levels. As a result, the design is not a standard central composite design.

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*Youden, W. J. and Steiner, E. H., Statistical Manual of the Association of Official Analytical Chemists, Arlington, Va., 1982; and Davies, O. L., Design and Analysis of Industrial Experiments, Great Britain, 1979.

TABLE 29. EXPERIMENTAL VARIABLES SELECTED FOR TESTING ALE SPRAY EQUIPMENT

Factor ID	Factor description	Quant./ qual.	No. of test levels
B	Booth air rate (linear velocity)	Quant.	2
C	Gun cleanliness (tip erosion)	Quant.	5
D	Restricted paint lines	Quant.	5
F	Voltage	Quant.	5
G	Electrode position	Qual.	3
Dummy	Dummy action or variable	Qual.	2

TABLE 30. ALE EXPERIMENTAL DESIGN

	Variable					
Run number	B	C	D	F	G	Dummy
1	-1	-1	-1	-1	-1	-1
2	1	1	-1	-1	-1	-1
3	-1	-1	1	-1	-1	1
4	-1	-1	-1	1	1	-1
5	1	1	1	-1	-1	1
6	1	1	-1	1	1	-1
7	-1	-1	1	1	1	1
8	1	-1	-1	1	-1	1
9	-1	1	-1	1	-1	1
10	1	-1	1	1	-1	-1
11	1	-1	-1	-1	1	1
12	-1	1	1	1	-1	-1
13	-1	1	-1	-1	1	1
14	1	-1	1	-1	1	-1
15	1	1	1	1	1	1
16	-1	1	1	-1	1	-1
17	1	-a	0	0	0	0
18	1	a	0	0	0	0
19	-1	0	-a	0	0	0
20	-1	0	a	0	0	0
21	1	0	0	0	0	-1
22	1	0	0	0	0	1
23	-1	0	0	-a	0	0
24	-1	0	0	a	0	0
25	1	0	0	0	-1	0
26	1	0	0	0	1	0
27	1	a	a	a	1	1
28	1	a	a	a	1	1
29	1	a	a	a	1	1
30	1	a	a	a	1	1
31	1	a	a	a	1	1
32	1	a	a	a	1	1

Where:

B = Booth air rates--test at 2 levels: 1,-1
C = Tip Erosion--test at 5 levels: a,1,0,-1,-a
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
F = Voltage--test at 5 levels: a,1,0,-1,-a
G = Electrode position--test at 3 levels: 1,0,-1
Dummy = Dummy variable not expected to impact TE

The last six runs of the test design are replicates. Replicates are provided at the base condition of all variables to provide a measure of the precision of the test.

ALE TEST PERFORMANCE

ALE testing began February 27, 1984. Equipment set up, target assembly and hanging, foil cutting and preweighing, and other preparatory tasks were completed earlier in the week. The paint was adjusted to desired specifications in a 20 L (5 gal) paint pot. Once the paint was adjusted, all equipment and lines were checked for proper installation and freedom from obstruction. The mass flow meter was calibrated and zeroed. Mass flow calibration was double checked against unatomized paint capture and found to be within 0.4 percent of the meter reading, as required.

Base level ("a") for each variable was determined by setting the equipment according to Graco experience with the test paint and spray painting system. Some adjustments were necessary to provide a good spray pattern without excessive laydown. Final base levels were confirmed by a visual spray pattern check. Base levels thus determined are shown in Table 31.

Deteriorated levels were selected by setting all factors except the subject variable (for each variable in turn) at the base level. The subject variable was changed until a significantly worse spray pattern could be discerned. The spray pattern was checked by spraying onto a paper target for 5 to 6 seconds, and observing the resulting pattern. Deteriorated variable levels ("-a") thus determined are shown in Table 31.

Intermediate levels were calculated to be evenly spaced from the base level ("a") to the deteriorated level ("-a"). Intermediate levels are also shown in Table 31.

Electrode position was similarly defined. Base level was with the electrode in normal position. Deteriorated level ("-a") was selected with the electrode clipped off. An intermediate level was decided as a bent electrode. All electrode position levels are shown in Figure 5. (Tip orientation was vertical for actual testing.)

Although gun cleanliness had been selected as an ALE experimental variable, a partially blocked tip could not be simulated. Any blockage affixed to the tip was blown out by the pressure of the paint during spraying.

TABLE 31. LEVELS OF OPERATING AND MAINTENANCE VARIABLES TESTED ON ALE SPRAY PAINTING EQUIPMENT

Factor	Quant/ qual.	No. of levels	Test levels
B. Booth air rate*	Quant.	2	1= 0.61m/s (120 ft/min) -1= 0.36m/s (70 ft/min)
C. Tip erosion†	Quant.	5+	a= 0.28 mm (.011 in.) cap 1= 0.28 mm (.011 in.) cap 0= 0.33 mm (.013 in.) cap -1= 0.38 mm (.015 in.) cap -a= 0.38 mm (.015 in.) cap
D. Restricted paint lines	Quant.	5	a= 9066.9 kPa (1300 psig)z 1= 8032.4 kPa (1150 psig) 0= 6997.9 kPa (1000 psig) -1= 5963.4 kPa (850 psig) -a= 4929.0 kPa (700 psig)
F. Voltage‡	Quant.	5	a= 72 kV 1= 63 kV 0= 54 kV -1= 45 kV -a= 36 kV
G. Electrode position	Qual.	3	1= normal 0= bent ++ -1= clipped off ††

---

*Actual booth air rates varied from 100 to 140 fpm for level "+1" and 50 to 90 fpm for level "-1." Average air velocities are used in this table.

†Gun cleaniness was interpreted as "worn tip" for this experiment. Progressively wider tip hole diameters were used to simulate tip wear.

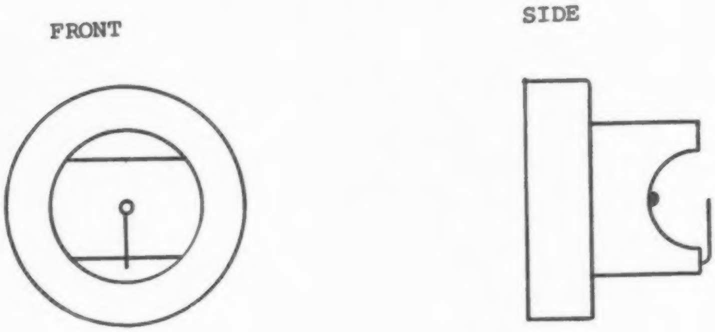
+The original experimental design called for 5 test levels; in practice we were only able to simulate 3 levels.

zMeasured at gun downstream of all paint filters.

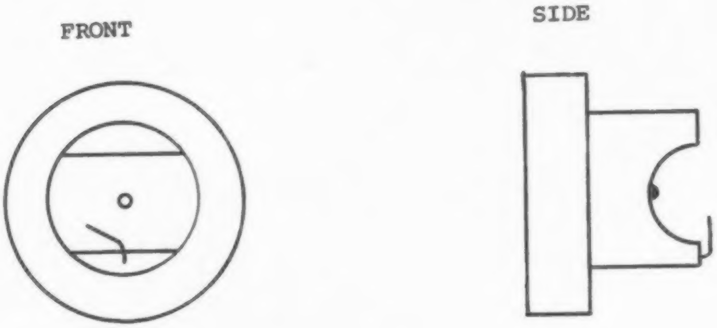
‡Monitored at power supply.

++Bent as shown in Figure 5.

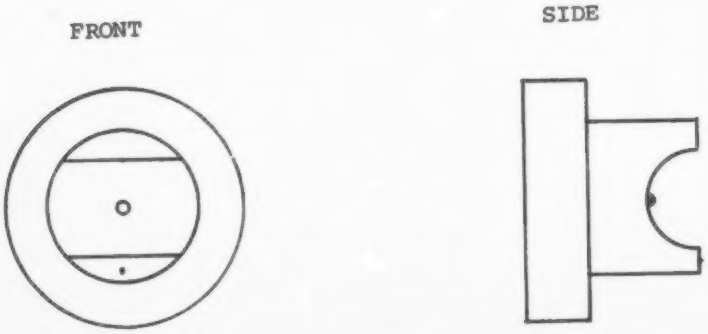
††Electrode cut off at plane of cap.



Level +a and +1: Normal electrode position



Level 0: Bent electrode



Level -a and -1: Electrode cut off

Figure 5. Airless electrostatic air cap showing test levels for electrode position

To salvage the variable, it was decided to look at another identified variable instead. The only other tip factor identified for ALE equipment was tip erosion. Abrasive paints can erode the tip orifice after prolonged use. To simulate tip erosion, tips at a variety of diameters were obtained and checked for spray pattern. Only three tips gave acceptable spray patterns, at 0.28 mm, 0.33 mm, and 0.38 mm diameters. With larger tips, the paint laydown was too heavy to avoid running; smaller tips were not avialable.

As in previous experiments, the booth air rate could only be controlled to two levels. Voltage and restricted paint lines were each simulated at five levels, as shown in Table 31.

Variable level selection was completed on February 27, 1984. ALE test runs were started on February 28, 1984. Weight-percent-solids samples were taken. The results were in close agreement, and testing began in randomized order according to the test plan.

Nine test runs were completed the first day of ALE testing. One run was thrown out due to a timer malfunction; one run was deleted because the booth water wash was not on; and one run was eliminated because grounding wires had not been attached to the foils (even though the flat panel was grounded).

Paint had to be added and adjusted for the second day of testing. All preparatory steps were taken, but on the first run the mass flow meter totalizer stuck. Mass flow measurements were lost, and the run was repeated immediately after repair of the malfunctioning switch. After eight runs were completed, the laboratory experienced a 2-1/2-hour power failure. When power was restored, all start-of-test QA/QC measures were repeated before resuming testing. Final weight-percent-solids determinations were made after 15 runs were completed. The morning and evening weight-percent-solids determinations agreed nicely, but the power failure sample was several weight-percent higher. The power failure sample had not been stirred during the power failure, and probably was not adequately stirred prior to sampling. This weight percent solids was omitted from TE calculations as a suspect sample.

Paint was added and viscosity adjusted for the final day of ALE testing. All prescribed preparatory steps were taken according to the test plan (Appendix A) and QA/QC plan (Appendix B). The rest of the experiment was completed without incident on March 1, 1984.

TEST RESULTS

Tests were run and calculations performed in accordance with the standard test method. Values of transfer efficiency obtained during testing are shown in Table 32.

TABLE 32. ALE TEST RESULTS

Run number	Percent transfer efficiency FP	VC	Graco
1	91.5	47.5	83.6
2	87.8	43.2	64.6
3	93.9	42.2	61.0
4	89.8	68.8	77.6
5	83.3	44.1	58.0
6	93.3	65.1	77.2
7	96.1	76.2	74.5
8	90.2	60.2	70.8
9	90.9	69.4	76.3
10	93.7	48.2	64.3
11	94.8	60.0	70.0
12	87.6	68.0	71.9
13	90.8	68.1	71.9
14	84.7	48.0	63.7
15	90.6	71.9	74.2
16	88.5	66.4	72.1
17	91.8	53.3	63.7
18	89.6	56.7	67.7
19	88.6	66.2	75.1
20	91.9	57.0	68.3
21	90.5	55.3	68.3
22	84.3	51.0	65.8
23	89.2	44.1	59.4
24	93.2	74.9	76.2
25	88.3	47.3	62.5
26	88.8	65.9	72.3
27	91.7	78.6	78.2
28	92.5	77.8	79.1
29	89.1	73.3	74.2, 76.2
30	90.4	75.9	79.3
31	92.6	80.8	78.7
32	93.4	76.6	76.8
33	----	----	78.2*

*An extra replicate using only the Graco targets was made for Graco's own purposes. The data is included here for completeness.

STATISTICAL ANALYSIS

The terminology shown below is used in the regressions that follow:

x_1=booth air rate (linear velocity)

x_2=tip erosion

x_3=restricted paint lines

x_4=voltage

x_5=electrode position

TE=transfer efficiency

In the case of the airless electrostatic, the following linear, quadratic, and interaction effects were chosen for the regression model.

- Linar in x_1
- Linear and quadratic in x_2
- Linear and quadratic in x_3
- Linear and quadratic in x_4
- Dummy variables in x_5
- Interaction between x_1 and x_3
- Interaction between x_3 and x_4
- Interaction between x_2 and x_3
- Interaction between x_1 and x_2

A discussion of how to use the regression equations is presented in the AAC Statistical Analysis section of this report. The derived regression for each target type follows.

Flat Panel Target

$$TE = 90.30 - 1.12x_2 + 1.37x_4 - 0.65x_1x_3$$

Only linear effects are significant for ALE testing of flat panel targets. Tip erosion, x_2, has a negative effect on TE. The positive coefficient on x_4, voltage, indicates that as voltage increases TE increases. Booth air rate, x_1, and restricted paint lines, x_3, produce a significant interaction.

The proportion of overall variance explained by the regression (R^2) is 0.28. This is the poorest case of all equipment types and target configurations tested. The raw data was reviewed to locate any test errors contributing to this unusually low R^2, but no experimental source was found. The low R^2 may be attributed to the low overall variation in this test series. The variation of TE over all of the experimental combinations was only 3.0. This value is barely above the standard deviation of the test procedure (2.0). The lack of variance demonstrates the insensitivity of the system to O&M factors. The standard deviation of replicated test runs was 2.287, high and not quite within the specified range of the test procedure. The error due to lack of fit is insignificant, with F = 0.38.

Vertical Cylinder Target

$$
\begin{aligned}
TE = {} & 57.31 - 3.77x_1 + 2.85x_2 - 1.55x_3 \\
& + 7.02x_4 - 4.66x_5d_1 + 8.62x_5d_2 \\
& - 1.80x_1x_2 + 1.56x_2x_3
\end{aligned}
$$

More than twice as many variables are significant for VC testing than were identified for FP testing. The negative coefficient on x_1 indicates that TE decreases with increasing booth air rates. The positive coefficient on tip erosion indicates that as tip diameter decreases, TE increases. But neither the booth air rate nor the tip erosion trends are constant because of the interaction between the two. The coefficient of the interaction is negative. Thus the negative effect of booth air is enhanced at the high level of tip erosion but is moderated at the low level of tip erosion. TE is adversely affected by increasing restrictions in the paint lines (x_3). However this negative trend is not constant, due to the interaction with tip erosion. Increasing voltage tends to increase TE dramatically. The magnitude and direction of the effects of different levels of electrode position changes with the selection of electrode position. Figure 5 shows the various test levels for electrode position.

Two interactions are significant for this case, tip erosion with booth air and tip erosion with restricted paint lines. Each effect acts in a different direction. Nevertheless, it is clear that tip erosion is the overwhelming factor for this case.

The proportion of overall variance explained by the regression (R^2) is 0.95, a respectable value. The standard deviation due to repeats is 2.55, slightly over the 2.0 value specified in the test procedure. The error due to lack of fit is insignificant, with F= 2.16 (P= 0.20).

Graco Target

$$TE = 69.05 - 2.83x_1 - 2.69x_3 + 3.21x_4 - 0.84x_4^2 + 4.71x_5d_2 + 0.80x_1x_2 + 1.63x_2x_3 + 1.32x_3x_4$$

The Graco target configuration identified the most significant O&M variables for ALE testing. Like the other cases, increasing booth air rates (x_1) causes a drop in TE. Restricted paint lines (x_3) also cause a drop in TE, while increasing voltage (x_4) raises TE linearly and causes it to slightly drop quadratically. Electrode position is significant at the d_2 ("+1") level only. At this level TE is increasing with changes in electrode position. Apart from the linear effects, interactions between x_1 and x_2, x_2 and x_3, and x_3 and x_4 complicate the system. The linear trends described above are distinct but the rates of change of TE with respect to x_1, x_3, and x_4 are not constant. As an example, the booth air rate effect is negative but is moderated at the high level of x_3, restricted paint lines.

The proportion of overall variance explained by the regression (R^2) is a modest 0.83. The standard deviation of replicate test runs on Graco targets was 1.274, well within the 2.0 specified by the test procedure. The error due to lack of fit was insignificant, with F= 3.04 (P= 0.14). Table 33 gives the value of the F-statistic and associated probability for each effect of significance.

Tables 34, 35, and 36 presents comparisons of predicted and observed values of transfer efficiency for each experimental condition for the flat panel, vertical cylinder, and Graco targets respectively.

ALE CONCLUSIONS

ALE test results showed the most difference in discrimination among target configurations. Only two variables were identified as significant for the flat panel target (tip erosion and voltage), and these were only marginally significant. The Graco and vertical cylinder targets identified four and five significant variables, respectively, not including several interactions between variables.

Voltage, booth air rate, restricted paint lines, and electrode position were significant factors for Graco and VC targets types. These results are consistent with findings from AAE and ALC experiments: where electrostatic forces are involved, voltage, booth air rate, and electrode position are important to establishing optimum TE. The higher the voltage and the

TABLE 33. ALE F-STATISTICS (F) AND ASSOCIATED PROBABILITIES (P)

	Flat Panel		Vertical Cylinder		Graco	
Effect	F	P	F	P	F	P
x_1	-	-	54.31	.0007	117.16	.0000
x_2	6.64	.05	22.94	.0049	-	-
x_3	-	-	9.53	.0272	111.94	.0000
x_4	4.85	.07	191.31	.0000	166.26	.0000
x_5d_1	-	-	10.09	.0246	-	-
x_5d_2	-	-	30.86	.0026	72.09	.0000
x_1x_2	-	-	8.61	.0325	7.67	.0006
x_1x_3	6.42	.05	-	-	-	-
x_2x_3	-	-	7.00	.0457	30.94	.0000
x_3x_4	-	-	-	-	32.82	.0000
x_4^2	-	-	-	-	10.30	.0001

TABLE 34. ALE-FP COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	91.50	89.39	2.10	87.08	91.70
2	87.80	88.45	-0.65	86.20	90.70
3	93.90	90.69	3.20	88.78	92.49
4	89.80	92.13	-2.33	90.08	94.18
5	83.30	87.16	-3.86	84.94	89.37
6	93.30	91.19	2.10	88.98	93.40
7	96.10	93.42	2.67	91.12	95.73
8	90.20	93.42	-3.22	91.12	95.73
9	90.90	89.89	1.00	88.52	91.27
10	93.70	92.13	1.56	90.08	94.18
11	91.80	90.69	4.10	88.78	92.59
12	87.80	91.19	-3.59	88.98	93.40
13	90.80	87.16	3.63	84.94	89.37
14	84.70	89.39	-4.69	87.08	91.70
15	90.60	89.89	0.70	88.52	91.27
16	88.50	88.45	0.04	86.20	90.70
17	91.80	91.41	0.38	89.73	93.09
18	89.60	89.17	0.42	87.63	90.72
19	88.60	89.00	-0.40	86.98	91.01
20	91.90	91.59	0.30	89.27	93.90
21	90.50	90.29	0.20	89.25	91.33
22	84.80	90.29	-5.99	89.25	91.33
23	89.20	87.55	1.64	85.24	89.86
24	93.20	93.03	0.16	91.02	95.04
25	88.30	90.29	-1.99	89.25	91.33
26	88.80	90.29	-1.49	89.25	91.33
27	91.70	90.62	1.07	88.72	92.51
28	92.50	90.62	1.87	88.72	92.51
29	87.10	90.62	-3.52	88.72	92.51
30	90.40	90.62	-0.22	88.72	92.51
31	92.60	90.62	1.97	88.72	92.51
32	93.40	90.62	2.77	88.72	92.51

TABLE 35. ALE-VC COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	47.50	47.86	-0.36	43.52	52.20
2	43.20	42.90	0.29	38.90	46.91
3	42.20	44.63	0.56	37.40	45.87
4	68.80	75.18	-6.38	71.01	79.34
5	44.10	42.93	1.16	39.15	46.72
6	65.10	70.22	-5.12	66.15	74.30
7	76.20	68.95	7.24	64.65	73.26
8	60.20	57.95	2.24	53.82	62.09
9	69.40	68.07	1.32	63.83	72.30
10	48.20	51.73	-3.53	47.58	55.88
11	60.00	57.20	2.79	53.05	61.36
12	68.00	68.10	-0.10	64.07	72.12
13	68.10	67.32	0.77	63.20	71.43
14	48.00	50.98	-2.98	46.86	55.09
15	71.90	70.25	1.64	68.14	72.37
16	66.40	67.34	-0.94	63.18	71.51
17	53.30	52.49	0.80	49.09	55.88
18	56.70	54.60	2.09	51.29	57.90
19	66.20	64.17	2.02	60.58	67.76
20	57.00	57.98	-0.98	54.25	61.71
21	55.30	53.54	1.75	50.85	56.23
22	51.00	53.54	-2.54	50.85	56.23
23	44.10	47.04	-2.94	43.45	50.63
24	74.90	75.11	-0.21	71.38	78.84
25	47.30	48.88	-1.58	46.38	51.38
26	65.90	62.16	3.73	59.84	64.49
27	78.60	77.28	1.31	74.80	79.77
28	77.80	77.28	0.51	74.80	79.77
29	73.30	77.28	-3.98	74.80	79.77
30	75.90	77.28	-1.38	74.80	79.77
31	80.80	77.28	3.51	74.80	79.77
32	76.60	77.28	-0.68	74.80	79.77

TABLE 36. ALE-GRACO COMPARISON OF PREDICTED VERSUS ACTUAL TRANSFER EFFICIENCIES

Observation number	Observed value	Predicted value	Residual	Lower 95% CL for mean	Upper 95% CL for mean
1	83.60	74.27	9.32	70.36	78.18
2	64.60	65.34	-0.74	61.42	69.25
3	61.00	62.99	-1.99	59.39	66.59
4	77.60	82.74	-5.14	78.48	87.01
5	58.00	60.59	-2.59	56.65	64.53
6	77.20	73.81	3.38	69.63	77.99
7	74.50	76.75	-2.25	72.77	80.73
8	70.80	70.77	0.02	66.84	74.70
9	76.30	73.17	3.12	69.83	76.51
10	64.30	64.77	-0.47	61.08	68.47
11	70.00	71.71	-1.71	67.78	75.63
12	71.90	73.71	-1.81	70.08	77.33
13	71.90	74.11	-2.21	69.85	78.37
14	63.70	60.43	3.26	56.32	64.53
15	74.20	74.35	-0.15	71.81	76.89
16	72.10	69.36	2.73	65.14	73.58
17	63.70	65.41	-1.71	62.81	68.01
18	63.70	67.01	0.68	64.37	69.66
19	75.10	77.25	-2.15	73.78	80.72
20	68.30	66.51	1.78	62.65	70.36
21	68.30	66.21	2.08	64.08	68.35
22	65.80	66.21	-0.41	64.08	68.35
23	59.40	62.09	-2.69	57.16	67.02
24	76.20	74.91	1.28	70.44	79.38
25	62.50	66.21	-3.71	64.08	68.35
26	72.30	70.92	1.37	68.35	73.48
27	78.20	77.93	0.26	75.35	80.50
28	79.10	77.93	1.16	75.35	80.50
29	76.20	77.93	-1.73	75.35	80.50
30	79.30	77.93	1.36	75.35	80.50
31	78.70	77.93	0.76	75.35	80.50
32	76.80	77.93	-1.13	75.35	80.50

lower the booth air rate, the better TE is likey to be. Thus, ALE spray painting equipment should be maintained to supply the maximum allowable voltage to the tip. Periodic checks of power supply are recommended to assure tip voltage remains at the desired level. Booth air rate should be kept to the lowest level acceptable for safety, environment, and worker comfort.

The effect of the position of the electrode in the atomized paint field is less clear, appearing significant in some cases and insignificant in other similar cases. It seems prudent, however, to maintain the electrode position well into the atomized paint field. Trimming the electrode is not recommended.

Restricted paint lines have a significant effect on TE for Graco and VC target types. This is a shared phenomenon with other equipment types. Pressure of the paint supply to the spray gun should be monitored to avoid degeneration through clogging or other restrictions. If the paint pressure is not monitored, the operator may notice a loss of spray quality, but he is likely to take an inappropriate action to remedy the problem. This situation is especially true for air-atomized spray systems where the operator may adjust the fan air or the atomizing air to counteract the effects of lower paint pressure. It is equally applicable for ALE spray systems.

SECTION 8

COMPARISON OF TARGETS

BACKGROUND

The Draft Standard Test Method (Appendix A) specified two sets of targets for spray painting in each test run. These targets are described in detail in Appendix A. The test targets consisted of a set of foil-covered aluminum vertical cylinders (VC) mounted in certain positions inside a wooden frame, and a set of foil strips mounted at certain spacing on a large flat stainless steel panel (FP). Both targets were suspended from an overhead conveyor for the test. The VC targets were designed to be somewhat representative of smaller, more open and intricate substrates. The FP targets were designed to be representative of large, relatively flat and closed substrates. The test results from a single transfer efficiency determination include a VC result and a FP result. These results have quite different values.

During the test program at Graco, a third set of targets (called Graco targets) were painted at the same conditions as the Draft Standard Test Method targets. These targets consisted of a set of ten 15.24 cm (6 in) wide metal panels mounted 15.24 cm (6 in) apart, and hanging 121.92 cm (48 in) long. The TE results from the center six targets were averaged to obtain a single TE value. The TE value obtained for this target type was different from the values obtained for VC or FP targets.

This chapter evaluates the transfer efficiency characteristics of all three target types for four equipment types to determine if any of the designs has special advantages over other targets for future testing.

COMPARISON OF FACTORS IDENTIFIED AS SIGNIFICANT

Table 37 presents a summary of the variables identified as significant for each target type and each equipment type. The Graco target configuration was the most sensitive, identifying 23 significant O&M variables (or interactions) over all equipment types. VC targets came in a close second by identifying 19 significant variables, followed by FP targets at only 13 significant variables.

TABLE 37. COMPARISON OF SIGNIFICANT FACTORS IDENTIFIED BY THREE TARGET CONFIGURATIONS

		Target configuration	
Equipment type	VC	Graco	FP
ALE	Booth air	Booth air *	
	Tip Eros.		Tip eros. (marg)
	Paint lines	Paint lines *	
	Voltage *	Voltage *	Voltage (marg)
	Elect. pos.	Elect. pos. *	
	Booth air x tip	Booth air x tip	
	Tip x paint lines	Tip x paint lines	
		Paint lines x volt.	
R squared	0.95	0.83	0.28
ALC	Tip eros. *	Tip eros. *	Tip eros. *
		Paint lines	
R squared	0.91	0.95	0.87
AAE	Air lines	Air lines	Air lines *
	Booth air	Booth air	
	Gun cleanliness	Gun cleanliness	
	Paint lines	Paint lines	Paint lines
	Fan air	Fan air	
	Voltage *	Voltage *	Voltage
	Electrode pos.	Electrode pos.	Electrode pos.
	Booth air x fan air		
R squared	0.92	0.94	0.67
AAC	Air lines *	Air lines *	Air lines *
	(Booth air-close)	Booth air	Booth air
		Gun cleanliness	
	Paint lines	Paint lines	Paint lines *
	Fan air	Fan air *	Fan air *
		----air lines x booth air----	
		---- booth air x fan ----	
R squared	0.79	0.96	0.99

* Strong response, overriding factor influencing TE
(marg) Marginally significant response

The variables identified by the Graco targets match up fairly consistently with those identified by VC's; FP targets presented some anomolies.

Graco targets had the highest correlation coefficients, averaging 0.92, followed closely by VC at 0.89 and FP at 0.70.

WORTH ASSESSMENT OF THREE TARGET CONFIGURATIONS

A Worth Assessment Model* was constructed to evaluate the relative merits of each target type. Six criteria were selected for this evaluation:

1. High correlation coefficient (ability to fit mathematical models)
2. Target discrimination (ability to identify significant effects)
3. Ease of fabricating the target
4. Ease of transporting/storing the target
5. Ease of use during testing
6. Target cost

Each of the targets was ranked from 0 (low) to 1 (high) for these criteria. The rank was multiplied by weighting factors and summed to generate a score. Several different weighting factor combinations were used in calculations to compare the effects on the final score.

In every case, the Graco target configuration scored highest. The Graco target scored consistently higher in almost all categories than VC or FP targets. The Graco targets were easier to handle, provided the best sensitivity to significant factors, and demonstrated a very good correlation coefficient.

The worth assessment scores for evenly weighted criteria were:

Graco	0.79
VC	0.50
FP	0.50

This case is the closest competition between target types Detailed computer printouts of this analysis, is shown in Table 38.

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*CENTEC Corporation, "Worth Assessment Model," computer software, Copyright 1979.

TABLE 38. WORTH ASSESSMENT MODEL COMPARING TARGET CONFIGURATIONS

(1) VC target

Factor name	Ranking	Selection description	Weight	Value
1 Correlation coefficient	1.0	Very high R squared	0.170	0.17000
2 Target TE discrimination	0.8	Identifies many factors	0.170	0.12750
3 Ease of fabrication	0.3	Difficult to make	0.170	0.04250
4 Ease of transport/storage	0.5	Moderately difficult to T&S	0.170	0.08500
5 Ease of use during test	0.0	Difficult to use and handle	0.170	0.07500
6 Cost of target	0.5	Moderate cost	0.150	0.07500
			Score	0.50000

(2) Graco target

Factor name	Ranking	Selection description	Weight	Value
1 Correlation coefficient	0.8	High R squared	0.170	0.12750
2 Target TE discrimination	1.0	Identifies most factors	0.170	0.17000
3 Ease of fabrication	0.8	Fairly easy to fabricate	0.170	0.12750
4 Ease of transport/storage	0.8	Fairly easy to trans. & store	0.170	0.12750
5 Ease of use during test	0.8	Fairly easy to use and handle	0.170	0.12750
6 Cost of target	0.8	Relatively inexpensive	0.150	0.11250
			Score	0.79250

(3) FP target

Factor name	Ranking	Selection description	Weight	Value
1 Correlation coefficient	0.8	High R squared	0.170	0.12750
2 Target TE discrimination	0.3	Identifies a few factors	0.170	0.04250
3 Ease of fabrication	1.0	Easy to fabricate	0.170	0.17000
4 Ease of transport/storage	0.3	Difficult to trans. & store	0.170	0.04250
5 Ease of use during test	0.3	Very inconvenient to use	0.170	0.04250
6 Cost of target	0.5	Moderate cost	0.150	0.07500
			Score	0.50000

APPENDIX A

DRAFT STANDARD METHOD FOR SPRAY PAINTING TRANSFER EFFICIENCY OPERATIONS AND MAINTENANCE TESTING*

1. SCOPE

1.1 This method covers testing to determine the effects of certain operating and maintenance factors on transfer efficiency. Four types of spray equipment, air atomized conventional (AAC), airless conventional (ALC), air atomized electrostatic (AAE), and airless electrostatic (ALE) are to be tested.

1.2 The factors selected for testing and the levels of each factor to be tested are summarized in the experimental design matrix for each type of spray equipment (Subtask Report, Tables 5, 6, 7, and 8).

1.3 This test program is estimated to take 4-5 weeks of laboratory work.

1.4 This method is applicable only to solvent or water-borne coatings applied in a single pass. The same coating shall be used for all tests in this program.

2. APPLICABLE DOCUMENTS

2.1 ASTM Standards:

- D-1200-70 Viscosity of Paints, Varnishes, and Lacquers by Ford Viscosity Cup
- D-2369-81 Standard Test Method for Volatile Content of Coatings
- D-1005-51 Measurement of Dry Film Thickness of Organic Coatings

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*Many conventional industrial units are used throughout the test procedure to accommodate participating laboratories and to minimize conversion errors on site. Metric conversions are made as required as shown in the conversion list at the front of the report.

- ASTM D1212-79 Measurement of Wet Film Thickness of Organic Coatings

- ASTM D2353-68 Flow Rating of Organic Coatings Using the Shell Flow Comparator

- ASTM D1475-60 Density of Paint, Varnish, Lacquer, and Related Products

2.2 ANSI/IEEE Metric Practice

3. SUMMARY OF METHOD

3.1 A battery of specially designed targets are covered with preweighed, labeled foil, then spray painted in a single pass under rigidly controlled conditions as specified in the test matrix. The foils are removed from the targets, cured, and weighed. The net weight gain is divided by the weight of paint sprayed at the targets to yield a single transfer efficiency determination.

3.2 The battery of targets is composed of 2 sets of 4 targets each. The first set of targets consists of 4 foils mounted in prescribed positions on a large steel plate. The mean weight gain for these 4 foils is used to calculate the transfer efficiency. This target configuration is intended to be representative of large, relatively flat industrial workpieces. The second set of targets consists of 4 foils mounted on widely spaced vertical cylinders. The mean weight gain for these 4 foils is used to calculate the transfer efficiency. This target configuration is designed to be representative of smaller, more intricate and open industrial workpieces.

3.3 A transfer efficiency determination shall be made for each set of conditions shown in each test matrix, except that runs will be performed in randomized order within each matrix.

3.4 Base conditions ("a") shall be established through a set of pre-test runs to determine levels of each factor at good spray conditions. Deteriorating levels ("1,0,-1,-a") of each factor will be determined from the base levels. The base level and deteriorating levels of each factor shall be determined prior to beginning each test matrix.

4. TEST TARGETS

4.1 Test targets consisting of a set of 1-1/4-inch diameter aluminum cylinders and a large stainless steel flat panel, configured as shown in Figure A-1 or Figure A-2, shall be used for this test.

5. TEST APPARATUS

5.1 Spray painting booth, preferably back-drawn with 100-fpm linear air velocity at the plane of the targets or, if not available, any booth meeting regulations for the type of spray system being tested may be used. The same spray booth shall be used for all tests of a series. The spray booth must be large enough to accommodate the prescribed targets. The spray booth must be equipped with a conveyor system capable of carrying the test panels past the spray equipment at the desired speed, and capable of at least 2 linear air rates.

5.2 Four complete systems (AAE, ALE, AAC, and ALC) for spray painting application, including spray gun, paint supply pot, power supply (if electrostatic), air supply lines, paint supply lines, power cables (if electrostatic), regulators, and pressure gages shall be used in this test.

5.3 Scales of suitable size and accuracy shall be used for paint mass flow rate determinations. Laboratory scales of suitable size and accuracy shall be used for weighing test foils. Accuracy of 0.01 percent is recommended as a minimum accuracy for scales.

5.4 Foil, mounted to cover vertical cylinder and flat test panels as shown in Figure A-1 and Figure A-2 shall be used. Six-inch wide 1.5-mil medium temper alloy foil shall be used for covering the test panels. The shiny side of the foil shall always face out.

5.5 A standard 10-minute stopwatch with 0.1-second accuracy shall be used.

5.6 Tape measure, graduated in 1/16 of an inch, 10 feet long, such as a rigid carpenters' rule, may be used.

5.7 Aluminum foil dish, 58 mm in diameter by 18 mm high with a smooth bottom surface shall be used.

5.8 Syringe, 5 ml, capable of dispensing the coating under test at sufficient rate that the specimen can be dissolved in solvent shall be used.

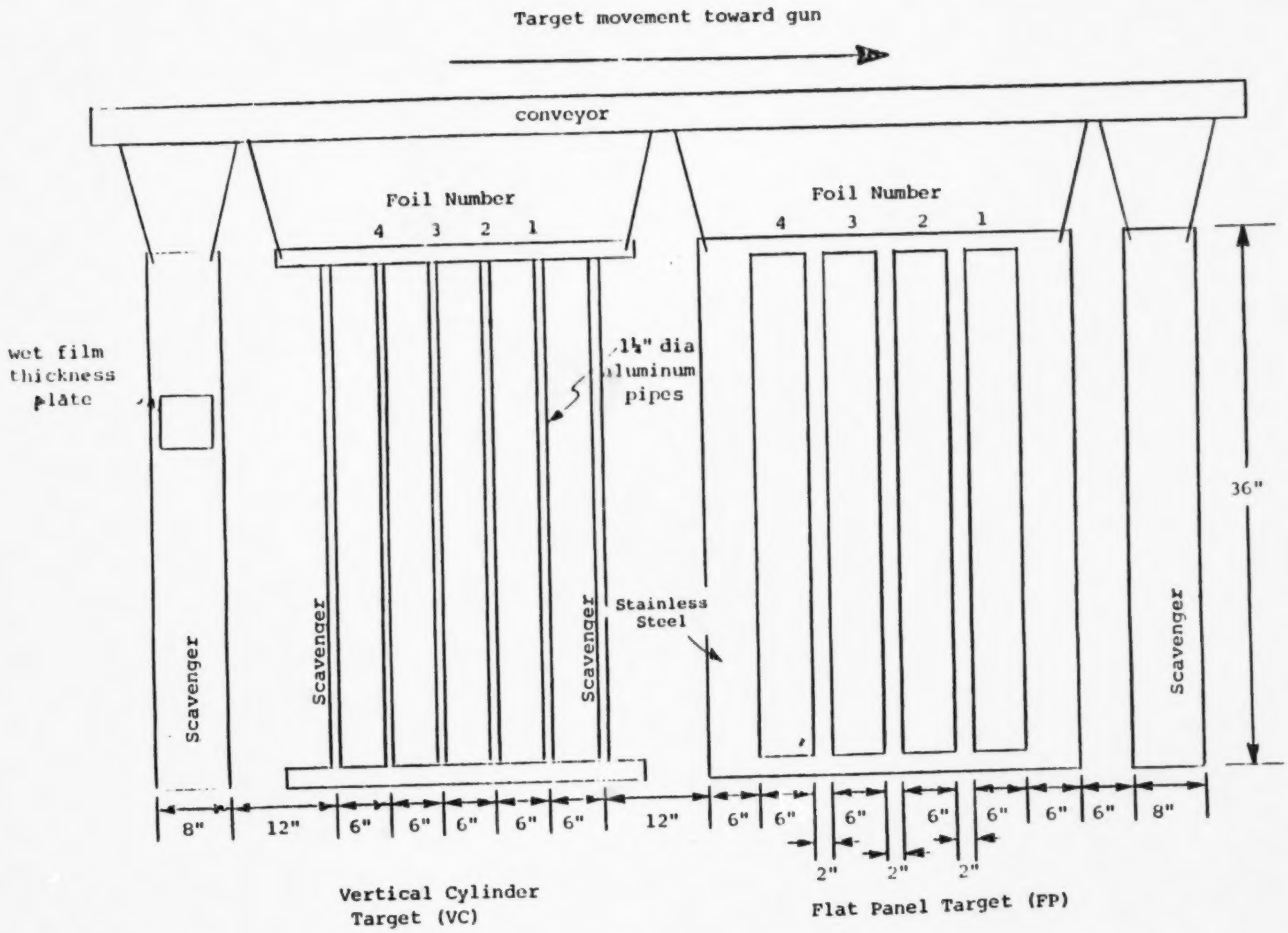

Target movement toward gun
conveyor
Foil Number
4 3 2 1
Foil Number
4 3 2 1
wet film thickness plate
1¼" dia aluminum pipes
Stainless Steel
Scavenger
Scavenger
Scavenger
Scavenger
36"
8"
12"
6"
6"
6"
6"
6"
12"
6"
6"
6"
6"
6"
6"
6"
8"
2"
2"
2"
Vertical Cylinder Target (VC)
Flat Panel Target (FP)

Figure A-1. Target Configurations for Air Atomized Conventional and Electrostatic Spray Guns

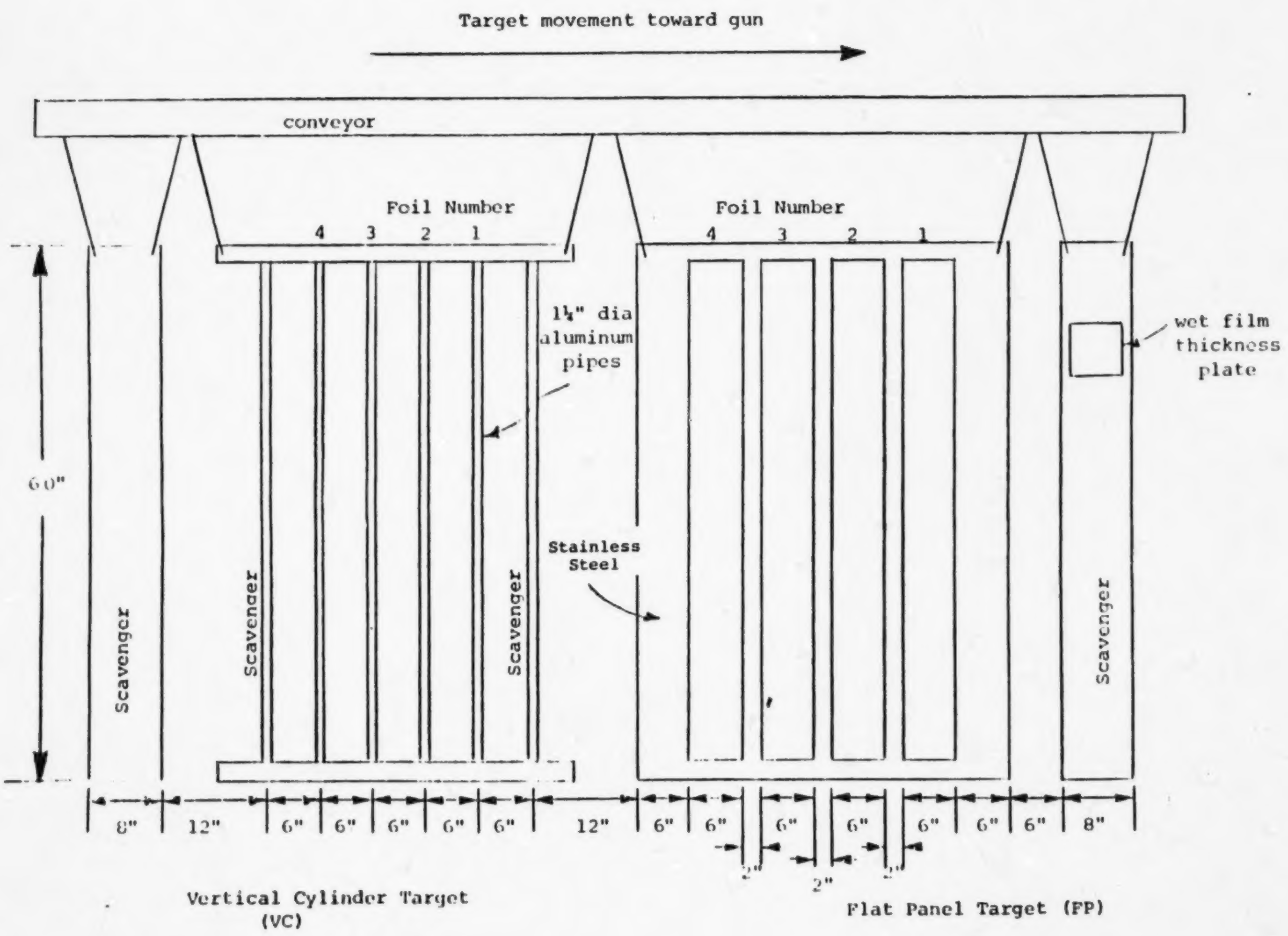

Target movement toward gun
conveyor
Foil Number
4
3
2
1
Foil Number
4
3
2
1
1¼" dia aluminum pipes
wet film thickness plate
60"
Scavenger
Scavenger
Scavenger
Stainless Steel
Scavenger
8"
12"
6"
6"
6"
6"
6"
12"
6"
6"
6"
6"
6"
6"
6"
8"
2"
2"
2"
Vertical Cylinder Target (VC)
Flat Panel Target (FP)

Figure A-2. Target Configuration for High Speed Bell

5.9 Forced draft curing oven, sufficient to hold a complete set of test foils and aluminum dishes, shall be used.

5.10 Wet film measurement gage.

5.11 Thermometer, with suitable range for spray and cure conditions, accurate to 0.2°F shall be used.

5.12 Anemometer, with suitable range for booth linear velocity, accurate to 3 percent of reading shall be used.

5.13 Test Notebook, a bound test notebook containing the test procedure, data sheets, reference methods, and QA/QC Plan shall be provided to the laboratory by CENTEC.

6. PROCEDURE AND CALCULATIONS

6.1 Perform calibration of the platform scale once per week or each time that it is moved and leveled, whichever occurs more frequently. Perform calibration of the laboratory scale once every test series. Calibrate all pressure gages per standard operating procedure prior to test.

6.2 Select test equipment for first test series. Using Data Sheet 1, document the test equipment specifications. Be sure to check all information and sign the form. Each data sheet shall be double checked by a second party, either engineer or technician, and signed off.

Data Sheet 1

Test Equipment Specifications

Test Date: ________ Test No.: ________ Data by/Checked by: ________

A. Weight Percent Solids Measurement Equipment
   1. Laboratory Scales
      a. Manufacturer ________
      b. Model No. ________
      c. Serial No. ________
      d. Capacity, g ________
      e. Rated accuracy, g ________
   2. Foil Dishes
      a. Type ________
      b. Size ________
   3. Syringe
      a. Type ________
      b. Capacity, mL ________
   4. Solvent Type ________

B. Conveyor Speed Measurement Equipment
   1. Rule
      a. Type ________
      b. Graduations ________
   2. Electronic Timer
      a. Type ________
      b. Manufacturer ________
      c. Model No. ________
      d. Serial No. ________
      e. Rated accuracy, s ________

C. Mass Flow Measurement Equipment
   1. Platform Scales
      a. Manufacturer ________
      b. Model No. ________
      c. Serial No. ________
      d. Capacity, kg ________
      e. Rated accuracy, g ________
   2. Stopwatch
      a. Manufacturer ________
      b. Model No. ________
      c. Serial No. ________
      d. Rated accuracy, s ________

D. Target Foil
   1. Type ________
   2. Nominal Thickness, mils ________
   3. Temper ________

E. Wet Film Measurement Equipment
      a. Manufacturer ________
      b. Model No. ________

6.3 Select coating. The same coating shall be used for all tests in this program. Using Data Sheet 2, document the paint characteristics. Paint characteristics shall be documented daily, at each addition of paint, and at other times as requested by the CENTEC engineer or GRACO representative. Again, check your information and sign the form.

Data Sheet 2

Paint Specifications

Test Date: __________ Test No.: __________ Data by/Checked by: ____________________

1. Paint Type ____________________
2. Resin Type ____________________
3. Manufacturer ____________________
4. Manufacturer's Paint ID No. ____________________
5. Lot No. ____________________
6. Color ____________________
7. Recommended Cure Schedule _____ min. @ _____ °F
8. Viscosity (uncut) _____ sec.# _____ Ford Cup @ _____ °F
9. Reducing Solvent ____________________
10. Vol. of Solvent Put into Vol. Paint _____ (vol) solvent in _____ (vol) paint
11. Viscosity - Spray (cut)* _____ sec.# _____ Ford Cup @ _____ °F
12. Wt./Gallon - Spray _____ lbs/gal
13. Wt. Solids - Spray _____ %
14. Resistivity or Conductance _____ MΩ _____ μA

---

*Use ASTM D-2353-68, ASTM D-1200-70, or ASTM D-3794 part 6.

6.4 Set up paint supply equipment and platform scale. Using Data Sheet 3, document the paint supply equipment specifications. Be sure to check your information and sign the form.

Data Sheet 3

Paint Spray and Peripheral Equipment Specifications

Test Date: ____________ Test No.: ____________ Data by/Chkd by: ____________

A. Paint Supply Tank

1. Type ____________
2. Manufacturer ____________
3. Model No. ____________
4. Serial No. ____________
5. Rated Capacity, gal ____________

B. Paint Spray Equipment

1. Type ____________
2. Manufacturer ____________
3. Model No. ____________
4. Serial No. ____________
5. Rated Capacity, cc/min ____________
6. Air Cap ____________
7. Fluid Tip ____________
8. Needle ____________

C. Paint Spray Booth

1. Type ____________
2. Manufacturer ____________
3. Model No. ____________
4. Serial No. ____________
5. Rated Capacity, cfm ____________

D. Conveyor

1. Type ____________
2. Manufacturer ____________
3. Model No. ____________
4. Serial No. ____________

E. Forced Draft Oven

1. Type ____________
2. Manufacturer ____________
3. Model No. ____________
4. Serial No. ____________

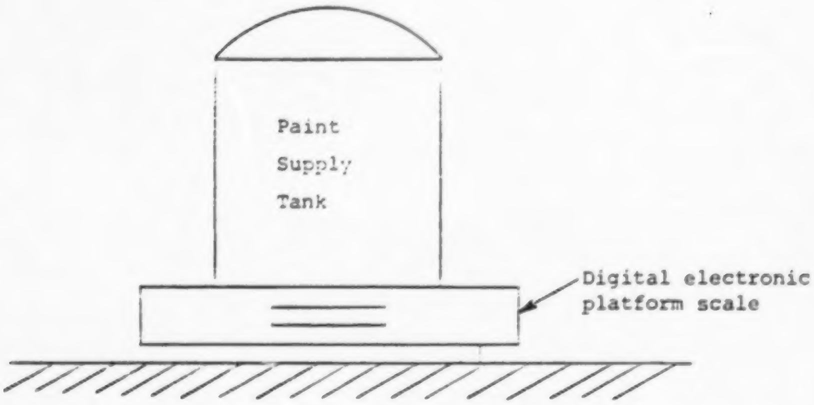
F. Paint Heaters

1. Type ____________
2. Manufacturer ____________
3. Model No. ____________
4. Serial No. ____________

6.5 For electrostatic spray equipment only, ground paint supply equipment and platform scale per Figure A-3. NOTE: In accordance with Section 9-8 of NFPA 33 for fixed electrostatic apparatus, measure resistance of equipment to ground (conveyor frame) to insure resistance is less than 1 x 10^6 Ohm.

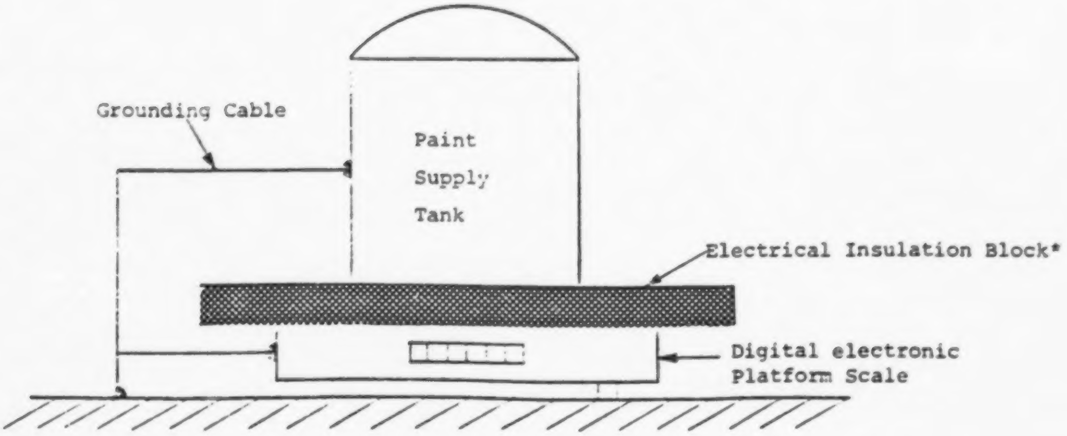
6.6 Using a small glass jar with an airtight lid, take paint grab sample from paint pot. ASTM D-3925-81 provides a good standard practice guide for paint sampling. Record test series number on label of jar.

6.7 Measure weight solids from paint sample. Use syringe weight difference technique as described in ASTM D-2369-81. Document the cure oven bake schedule and temperature on Data Sheet 4. Be sure you use the cure schedule recommended by the manufacturer on Data Sheet 2. Record raw data and results on Data Sheet 5. Paint weight percent solids should be determined before each test series, at the start of each test day, periodically between tests, and at the end of each test day. The participating laboratory shall store all weight percent solids samples until notified by CENTEC that the data analysis is complete.



Arrangement A
Nonelectrostatic Equipment

Paint
Supply
Tank
Digital electronic platform scale



Arrangement B
Electrostatic Equipment

Grounding Cable
Paint
Supply
Tank
Electrical Insulation Block*
Digital electronic Platform Scale

*Block must be capable of preventing current flow from supply tank to ground through the platform scale.

Figure A-3. Set-up for Paint Supply Equipment and Platform Scales

Data Sheet 4

Equipment Operating Conditions

Test Date: ____________ Test No.: __________ Data by/Chkd by: _________________

A. Paint Spray Equipment
  1. Paint Pressure at Paint Pot, psig ____________
  2. Paint Pressure at Spray Gun, psig ____________
  3. Atomizing/Turbine Air Pressure at Spray Gun, psig ____________
  4. Operating Voltage, kV ____________
  5. Disk or Bell Speed, rpm ____________
    a. With Paint Applied ____________
    b. Without Paint Applied ____________
  6. Shaping Air for Bell, psig ____________
  7. Paint Temperature at Paint Pot, °F ____________
  8. Gun to target distance, cm ____________
  9. Pump Setting ____________

B. Paint Spray Booth
  1. Ambient Temperature, °F ____________
  2. Relative Humidity, % ____________
  3. Air Flow Velocity, fpm ____________
  4. Air Flow Direction ____________

C. Target Parameters
  1. Average Wet Film Thickness, mils ____________
  2. Average Dry Film Thickness ____________
  3. Vertical Paint Coverage, cm (in) ____________
  4. Target Height, cm (in) ____________
  5. % Vertical Coverage ____________
  6. Resistance to Ground, Ohm ____________

D. Forced Draft Oven*
  1. Cure Time, minutes
    a. Foil Dish (sample) ____________
    b. Target Foil ____________

  2. Cure Temperature, °F
    a. Foil Dish (sample) ____________
    b. Target Foil ____________

E. Paint Heaters
  1. Temperature In, °F ____________
  2. Temperature Out, °F ____________

F. Conveyor Speed Setpoint, fpm (cm/sec) ____________

*Same cure schedule as foils.

Data Sheet 5

Weight Solids Test Data & Results

Test Date:	Test No.:	Data by/Chkd by:
________	________	____________

	Sample A	Sample B	Average
1. Syringe Weight			
a. Full, g	_____	_____	
b. Empty, g	_____	_____	
c. Net Wet Paint, g	_____	_____	
2. Dish Weight			
a. After Drying, g	_____	_____	
b. Empty, g	_____	_____	
c. Net Dry Solids, g	_____	_____	
3. % Weight Solids (2c/1c)	_____	_____	______A3

NOTES:

1. Actual Cure Schedule ________ min. @ ____________°F

Refer to ASTM 2369-81, Procedure B of "Standard Test Method for Volatile Content of Coatings."

6.8 Set up the paint spray equipment. Using Data Sheet 3, document specifications for the paint spray equipment and spray booth used in this test. Check your information and sign the data sheet.

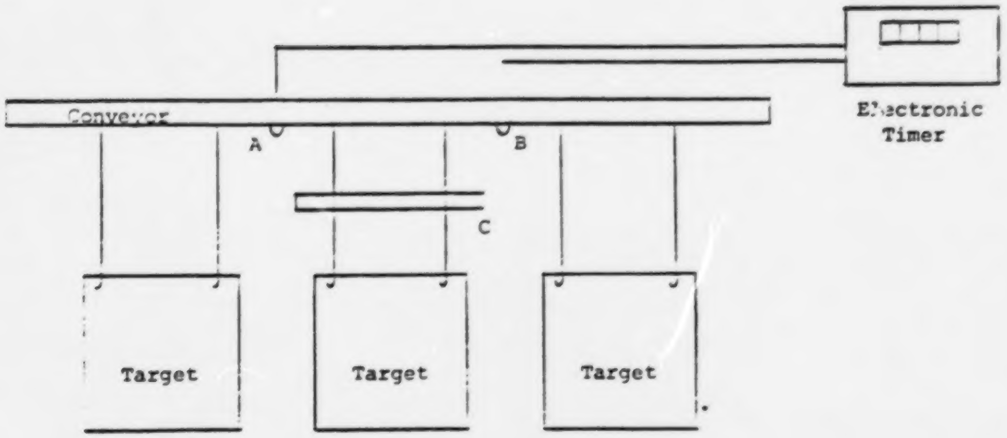
> NOTE: Equipment selection, equipment condition, paint selection, target configuration, and operating conditions have a substantial effect on transfer efficiency. Care should be taken to use the same booth and spray equipment, paint, targets, and operating conditions as specified for the run in the test matrix (Data Sheet 4, Sections A, B, C, and 6a, Sections ld, lc, 3, and 4) from test to test for comparable results.

6.9 Set up the conveyor speed measuring equipment. This equipment may consist of photoelectric cells or limit switches used in conjunction with an automatic digital timer. Alternatively, the conveyor speed may be measured using timing marks (chalk marks) on the conveyor in conjunction with a hand held stopwatch. Figure A-4 shows the permissible methods for conveyor speed measurement. Using Data Sheet 6a, record the horizontal distance between the photo cell or limit switch on/off positions.

6.10 Determine base level of each test factor which will produce a reasonably good spray pattern and finish. If base level has already been determined for test series, proceed to 6.13. The CENTEC engineer in agreement with the laboratory representative shall determine "reasonably good spray pattern and finish." Base level shall be determined only once for each test series. Base level is denoted by "a" in the test matrix.

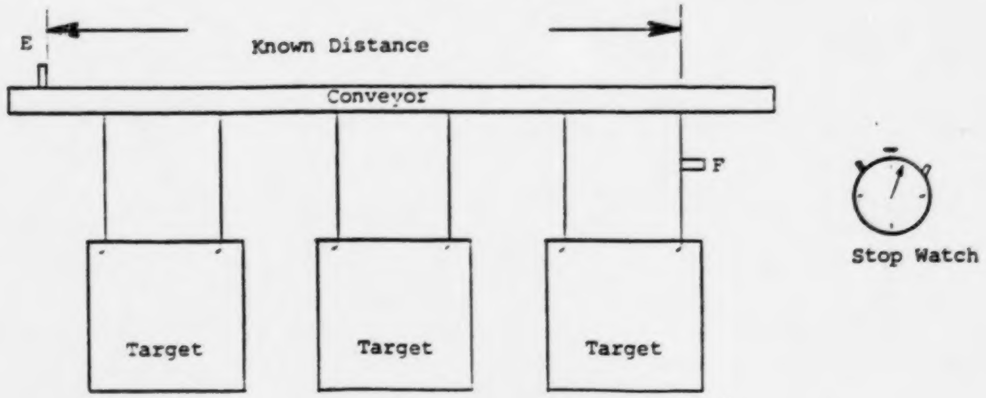
6.11 Determine deteriorating levels of each test factor to be examined in this test series. Selection shall be made by reducing the level of each factor to a point where an obvious impact on spray pattern and finish is noted. Again, the CENTEC engineer in agreement with the laboratory representative shall determine the level where spray pattern and finish is obviously poor. This level is the poorest value of each factor. It is denoted by "-a" in the test matrix.

METHOD A


Conveyor
A
B
C
Target
Target
Target
Electronic Timer

A = Stationary photoelectric cell or limit switch
B = Stationary photoelectric cell or limit switch
C = Moving plate of known width

METHOD B


E
Known Distance
Conveyor
F
Target
Target
Target
Stop Watch

E = Fixed timing mark
F = Moving timing mark

Figure A-4. Permissible Methods for Measuring Conveyor Speed

6.12 Levels "1," "0," and "-1" shall be selected at even absolute spacing from the value of each variable "a" to "-a."

6.13 The value of "a", "1", "0", "-1", and "-a" shall remain fixed for each variable through a test series.

6.14 Set up targets in accordance with Figure A-1 or A-2, as appropriate. Target configuration, material, and spacing is critical. Scavengers are metallic, as is the FP target. Cut 6-inch-wide aluminum foil strips to required length for each target. Label each foil strip with the appropriate nomenclature. (Nomenclature is shown on Table A-1.) Weigh each foil strip and record value on foil and on Data Sheet 6b. Check your information and sign the data sheet.

6.15 Attach foils to the vertical cylinder and/or flat panel targets as shown on Figure A-5 or A-6, as appropriate. Perform resistance check to verify adequacy of grounding. Per NFPA 33 Section 9-8, resistance shall be less than 1 x 10^6 ohms.

6.16 In accordance with Figure A-1 or A-2, attach shim stock to scavenger in order to measure wet film thickness.

6.17 Adjust all equipment operating parameters, i.e., gun to target distance, paint pot pressure, turbine air pressure, etc., to base values. Set factor levels to values required for this test run in the matrix. Record equipment operating parameters on Data Sheet 4. Check your data and sign the data sheet. NOTE: In accordance with Section 9-7 of NFPA 33 for fixed electrostatic apparatus, the gun to target distance shall be at least twice the sparking distance.

NOTE: Equipment selection, equipment condition, paint selection, target configuration, and operating conditions have a substantial effect on transfer efficiency. Care should be taken to use the same booth and spray equipment, paint, targets, and operating conditions (Data Sheet 4, Sections A, B, C, and 6a, Sections 1d, 1c, 3, and 4) from test to test for comparable results.

6.18 Check spray equipment and parameters to assure they are correct for this run.

TABLE A-1. NOMENCLATURE FOR SPRAY PAINTING TRANSFER EFFICIENCY TESTS

Each test foil will be labeled in 5 segments as follows:

1. Spray Equipment Type

   Air atomized conventional : AAC

   Airless conventional : ALC

   Air atomized electrostatic : AAE

   Airless electrostatic : ALE

2. Target Configuration

   Flat Panel : FP
   Vertical Cylinder: VC

3. Target Position: 1, 2, 3, or 4.

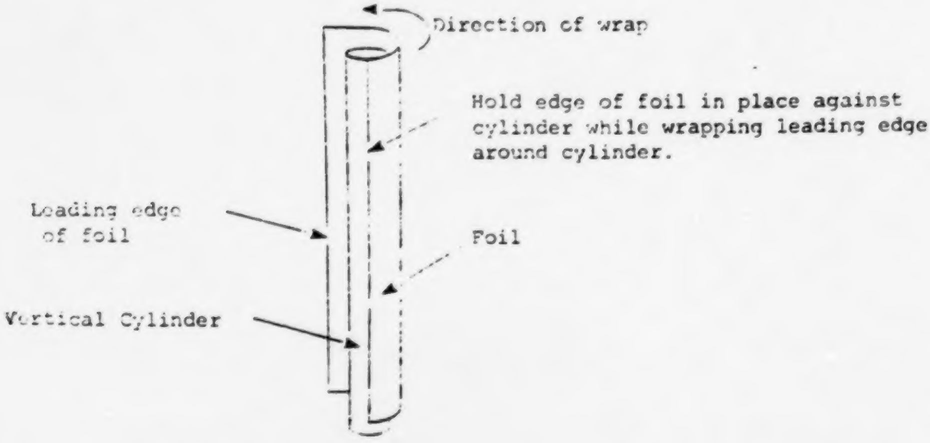
4. Test Series Identifier (letter or number)

Example: AAC-FP2-12

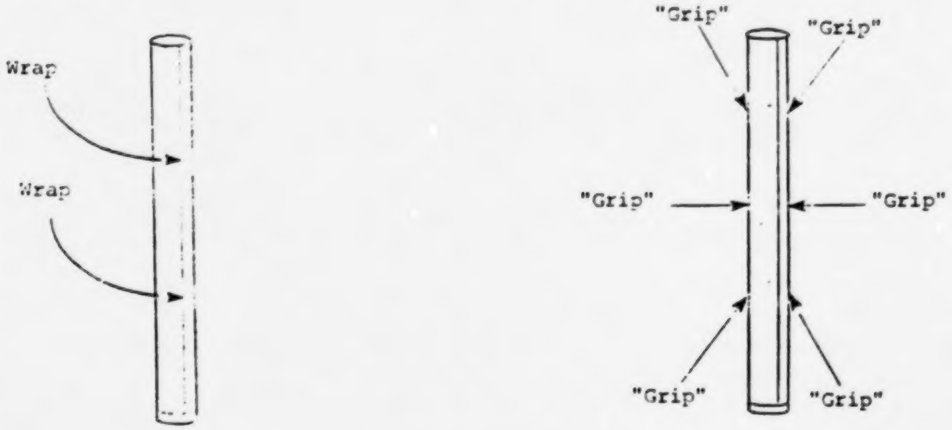
where AAC = air atomized conventional spray equipment

FP2 = the second flat panel target

12 = test run identifier


Direction of wrap
Hold edge of foil in place against cylinder while wrapping leading edge around cylinder.
Leading edge of foil
Foil
Vertical Cylinder

1. Wrap vertical cylinder targets with cylinders mounted on target bracket (See Figure 3 and 4). Wrap so the leading edge forms a seam away from the direction of spray.


Wrap
Wrap
"Grip"
"Grip"
"Grip"
"Grip"
"Grip"
"Grip"

As leading edge overlaps starting edge, solidly "grip" foil into place by grasping foil-covered cylinder.

Secure foil on cylinder by gripping the length of the cylinder. Foil will have a uniformly wrinkled surface.

Figure A-5. Vertical Cylinder Wrapping Technique

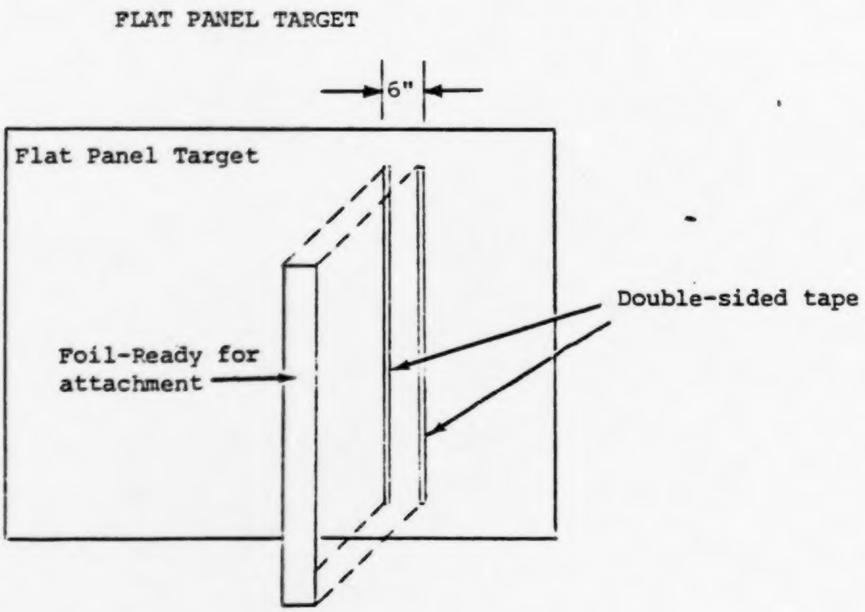

FLAT PANEL TARGET
6"
Flat Panel Target
Double-sided tape
Foil-Ready for attachment

Figure A-6. Flat Panel Foil Attachment Technique

Data Sheet 6a

TE Test Data and Results

Test Date: ________ Test No.: ________ Data by/Checked by: ____________

A. Weight Percent Solids (from Data Sheet 5) ________ A3

B. Total Solids Sprayed

1. Paint Spray Flow Rate

   a. Beginning Weight, g ____________

   b. End Weight, g ____________

   c. Time Between Weighings, s ____________

   d. Flow Rate, g/s ____________Bld

2. Conveyor Speed

   a. Distance Between Marks, cm ____________

   b. Time Between Marks, s ____________

   c. Speed, cm/s ____________B2c

3. Total Effective Target Width, cm* 15.24 B3

4. Total Solids Sprayed at Each Target, g (A3 x Bld x B3/B2c) ____________B4

5. Micromotion-metered paint mass flow rate, g/s ____________Bld′

---

* Total effective target width is six inches per foil on flat panel target (on 6" centers), and six inches per cylinder on vertical cylinder target (also on 6" centers). Six inches = 15.24 cm.

6.19 For electrostatic spray equipment, measure the gun tip operating voltage (with lines full of paint, but gun not operating). Adjust to desired voltage and record on Data Sheet 4.

6.20 Check conveyor clock, stopwatch, micromotion meter and platform scale to ensure that all have been zeroed (reset) and that the scales are in the tare mode.*

6.21 Turn on conveyor. As the leading edge of the first scavenger passes in front of the gun, turn on paint spray equipment and initiate flow; simultaneously, start stopwatch and record scale reading.

6.22 As the trailing edge of the last scavenger passes in front of the gun area, stop stopwatch and paint spray flow simultaneously. Turn off conveyor. Record platform scale, conveyor clock, micromotion meter flow rate, and stopwatch readings on Data Sheet 6a. Check the data and sign the data sheet.

6.23 Measure wet film thickness on shim plate and record on Data Sheet 4, line C-1.

6.24 Remove foils from targets, making sure no tape has stuck to the targets and no paint is lost. Securely attach coated foils to oven racks so all painted surfaces are exposed for uniform drying. Spring clips or tacks may be used to mount wet targets on racks. Insert racks in oven and bake at recommended schedule per Data Sheet 2. Flash time (the time between spraying and getting the targets into the oven) should be kept to a minimum. Set oven timer per recommended schedule.

6.25 Remove foils from oven and record actual bake schedule on Data Sheet 4. Weigh foils and record weight on each foil and on Data Sheet 6b. After weighing, store foils in appropriately labeled plastic bags, i.e., bags that have test run number identified. The laboratory shall retain all samples until data analyses are complete. Check all data for correctness and completeness. Both the engineer and technician must check and sign all data sheets before proceeding.

Replicates of each test run shall be made immediately after the original run, if required.

---

*During 10 tests, check micromotion meter vs manual determinations. If within precision requirements (see QA/QC Plan), use only micromotion meter thereafter.

Data Sheet 6b

TE Test Data and Results

Test Date: ____________ Test No.: ____________ Data by/Checked by: ____________________

C. Total Solids on Target

Flat Panel Target

Foil Weight After Drying, g:

Foil # 1 2 3 4 Total

________ + ________ + ________ + ________ = ________

Foil Weight Before Spraying, g:

________ + ________ + ________ + ________ = ________

Net Dry Solids, g: ________

D. Vertical Cylinder Target

Foil Weight After Drying, g:

Foil # 1 2 3 4 Total

________ ________ ________ ________ ________

Foil Weight Before Spraying, g:

________ ________ ________ ________ ________

Net Dry Solids, g: ________

E. Transfer Efficiency (by weight)[1]

Flat Panel Target ____________________

Vertical Cylinder Target ____________________

---

[1] $$\text{TE} = \frac{(\text{Net Dry Solids, g}) \times 100\%}{(\text{"Total Solids Sprayed at Each Target, g" from Data Sheet 6a}) \times (4 \text{ targets})}$$

6.26 Perform TE calculations as indicated on Data Sheet 5, 6a, and 6b using the weight solids determined for the test series. Document results on Data Sheet 6b, noting that each transfer efficiency observation is the mean of the transfer efficiency for 4 foils.

6.27 Repeat above steps (6.2 through 6.26) for each test run.

6.28 Be sure all data sheets have been properly completed, checked, and signed.

6.29 Record transfer efficiency in appropriate column on Data Sheet 7. When roughly 70 percent of the runs in a series are complete, the CENTEC engineer shall transmit the TE results to Dr. Ray Myers at 703-961-5638. Dr. Myers shall perform an outlier analysis and respond to the engineer within 24 hours. Outlier runs will be repeated as resources allow.

6.30 To proceed with the next run in a series, go to 6.10. To begin a new test series, go to 6.1.

6.31 CENTEC shall retain all original data sheets and the test notebook.

Data Sheet 7

Air Atomized Conventional Test

	FACTOR					TE Result	
Run Number	A	B	C	D	E	FP	VC
1	-1	-1	-1	-1	1		
2	-1	-1	-1	1	-1		
3	-1	-1	1	-1	-1		
4	-1	1	-1	-1	-1		
5	1	-1	-1	-1	-1		
6	1	1	1	-1	-1		
7	1	1	-1	1	-1		
8	1	1	-1	-1	1		
9	1	-1	1	1	-1		
10	1	-1	1	-1	1		
11	1	-1	-1	1	1		
12	-1	1	1	1	-1		
13	-1	1	1	-1	1		
14	-1	1	-1	1	1		
15	-1	-1	1	1	1		
16	1	1	1	1	1		
17	-a	-1	0	0	0		
18	a	-1	0	0	0		
19	0	1	-a	0	0		
20	0	1	a	0	0		
21	0	-1	0	-a	0		
22	0	-1	0	a	0		
23	0	1	0	0	-1		
24	0	1	0	0	1		
25	a	1	a	a	1		
26	a	1	a	a	1		
27	a	1	a	a	1		
28	a	1	a	a	1		
29	a	1	a	a	1		
30	a	1	a	a	1		

Where:

A = Restricted air lines--test at 5 levels: a,1,0,-1,-a
B = Booth air rates--test at 2 levels: 1,-1
C = Gun cleanliness--test at 5 levels: a,1,0,-1,-a
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
E = Fan air--test at 3 levels: 1,0,-1

Data Sheet 7

Airless Conventional Test

	FACTOR				TE Result	
Run Number	B	C	D	Dummy	FP	VC
1	-1	-1	-1	-1		
2	1	-1	-1	-1		
3	-1	1	-1	-1		
4	-1	-1	1	-1		
5	-1	-1	-1	1		
6	1	1	-1	-1		
7	1	-1	1	-1		
8	1	-1	-1	1		
9	-1	1	1	-1		
10	-1	1	-1	1		
11	-1	-1	1	1		
12	1	1	1	-1		
13	1	1	-1	1		
14	-1	1	1	1		
15	1	-1	1	1		
16	1	1	1	1		
17	1	-a	0	0		
18	1	a	0	0		
19	-1	0	-a	0		
20	-1	0	a	0		
21	1	0	0	-1		
22	1	0	0	1		
23	1	a	a	1		
24	1	a	a	1		
25	1	a	a	1		
26	1	a	a	1		
27	1	a	a	1		
28	1	a	a	1		

Where:

B = Booth air rates--test at 2 levels: 1,-1
C = Gun cleanliness--test at 5 levels: a,1,0,-1,-a
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
Dummy = Dummy variable not expected to affect TE

Data Sheet 7

Air Atomized Electrostatic Test

	FACTOR							TE Result	
Run Number	A	B	C	D	E	F	G	FP	VC
1	-1	-1	-1	-1	-1	-1	-1	____	____
2	1	1	1	-1	-1	-1	1	____	____
3	-1	-1	-1	1	1	1	-1	____	____
4	1	1	1	1	1	1	1	____	____
5	1	-1	-1	1	1	-1	1	____	____
6	-1	1	1	1	1	-1	-1	____	____
7	1	-1	-1	-1	-1	1	1	____	____
8	-1	1	1	-1	-1	1	-1	____	____
9	-1	-1	1	-1	1	-1	1	____	____
10	1	1	-1	-1	1	-1	-1	____	____
11	-1	-1	1	1	-1	1	1	____	____
12	1	1	-1	1	-1	1	-1	____	____
13	1	-1	1	1	-1	-1	-1	____	____
14	-1	1	-1	1	-1	-1	1	____	____
15	1	-1	1	-1	1	1	-1	____	____
16	-1	1	-1	-1	1	1	1	____	____
17	-a	-1	0	0	0	0	0	____	____
18	a	-1	0	0	0	0	0	____	____
19	0	1	a	0	0	0	0	____	____
20	0	1	-a	0	0	0	0	____	____
21	0	-1	0	-a	0	0	0	____	____
22	0	-1	0	a	0	0	0	____	____
23	0	1	0	0	-1	0	0	____	____
24	0	1	0	0	1	0	0	____	____
25	0	-1	0	0	0	-a	0	____	____
26	0	-1	0	0	0	a	0	____	____
27	0	1	0	0	0	0	-1	____	____
28	0	1	0	0	0	0	1	____	____
29	a	1	a	a	1	a	1	____	____
30	a	1	a	a	1	a	1	____	____
31	a	1	a	a	1	a	1	____	____
32	a	1	a	a	1	a	1	____	____
33	a	1	a	a	1	a	1	____	____
34	a	1	a	a	1	a	1	____	____

Where:

A = Restricted air lines--test at 5 levels: a,1,0,-1,-a
B = Booth air rates--test at 2 levels: 1,-1
C = Gun cleanliness--test at 5 levels: a,1,0,-1,-a
D = Restricted paint lines--test at 5 levels: a,1,0,-1,-a
E = Fan air--test at 3 levels: 1,0,-1
F = Voltage--test at 5 levels: a,1,0,-1,-a
G = Electrode position--test at 3 levels: 1,0,-1

APPENDIX B

QUALITY ASSURANCE/QUALITY CONTROL PLAN SENSITIVITY STUDIES ON THE EFFECTS ON TRANSFER EFFICIENCY OF IMPROPERLY MAINTAINED OR OPERATED SPRAY PAINTING EQUIPMENT

CENTEC Corporation
Reston, Virginia 22090

CONTRACT NO. 68-03-1721, Task 1

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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JANUARY 1984

TABLE OF CONTENTS

Page

SECTION 1 INTRODUCTION B-3

SECTION 2 PROJECT DESCRIPTION B-4

SECTION 3 PROJECT ORGANIZATION AND RESPONSIBILITY . . B-6

SECTION 4 QA OBJECTIVES FOR MEASUREMENT DATA IN TERMS OF PRECISION, ACCURACY, COMPLETENESS, REPRESENTATIVENESS AND COMPARABILITY B-8

SECTION 5 SAMPLING PROCEDURE B-10

SECTION 6 SAMPLE CUSTODY B-11

SECTION 7 CALIBRATION PROCEDURES, ANALYTICAL PROCEDURES AND FREQUENCY B-12

SECTION 8 DATA REDUCTION, VALIDATION, AND REPORTING . B-13

SECTION 9 INTERNAL QUALITY CONTROL CHECKS B-15

SECTION 10 PERFORMANCE OF SYSTEM AUDITS B-16

SECTION 11 PREVENTATIVE MAINTENANCE B-17

SECTION 12 SPECIFIC ROUTINE PROCEDURES TO ASSESS DATA PRECISION, ACCURACY AND COMPLETENESS B-18

SECTION 13 CORRECTIVE ACTION B-21

SECTION 14 QUALITY ASSURANCE REPORTS TO MANAGEMENT . . B-22

SECTION 1

INTRODUCTION

This quality assurance/quality control (QA/QC) plan assures collection of high quality data and insures consistent quality control measures for data developed under "Sensitivity Studies on the Effects on Transfer Efficiency of Improperly Maintained or Operated Spray Painting Equipment," Contract No. 68-03-1721. Under this contract, CENTEC Corporation will be conducting tests using a draft standardized method to determine the effect of operating and maintenance parameters on transfer efficiency (TE).

SECTION 2

PROJECT DESCRIPTION

Sensitivity studies on the effects of TE of improperly maintained or operated spray painting equipment will be conducted in this test program. A draft standardized TE method will be used for all tests in this program. The draft standard TE test method consists of passing a prescribed set of preweighed targets in front of spray equipment under rigidly controlled conditions in an industrial laboratory spray booth. The cured painted targets are weighed, and the original weight subtracted from the final weight to obtain the net dry solids deposited on the targets. The net dry solids is divided by the total solids sprayed at the targets, which is then multiplied by 100 percent to determine TE. A complete description of the draft standard TE test method is contained in Appendix A of the Subtask Report for this contract.

Four types of spray equipment will be tested during this program: air atomized conventional (AAC), airless conventional (ALC), air atomized electrostatic (AAE), and airless electrostatic (ALE). Each type of equipment has an individual experimental design. Five operation and maintenance (O&M) factors have been selected for testing on conventional spray equipment. These factors include booth air rates, atomizing air pressure, fan air, paint pressure, and cleanliness of the spray gun. Qualitative factors (booth air rate and fan air) will be tested at a minimum of two levels each, while quantitative factors (atomizing air, cleanliness, and paint pressure) will be tested at five levels. Levels will be selected for testing based on an original set-up with a good spray pattern. For electrostatic guns these factors will be tested as described, except two more factors, tip voltage and electrode position, will also be tested. Tip voltage will be tested at five levels, while electrode position will be tested at three. Six replicates are provided for each equipment type.

The four experimental designs are planned to provide enough data to support development of a response surface and regression equations to describe the response surface. A complete description of the experimental design is included in the Subtask Report for this contract.

Negotiations are underway with an industrial laboratory to arrange the test program. Testing is scheduled to begin in February 1984, and will last approximately one month.

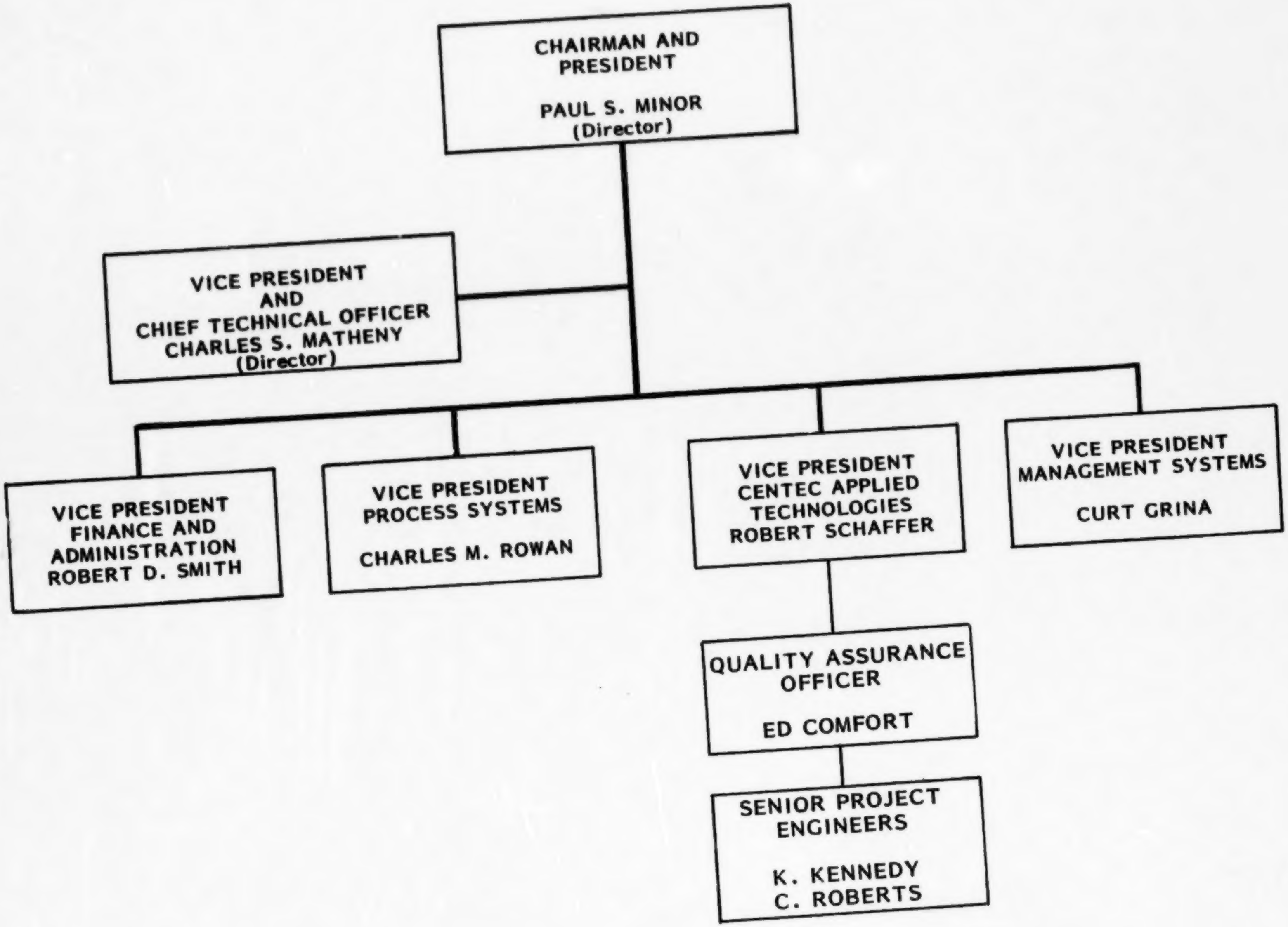
SECTION 3

PROJECT ORGANIZATION AND RESPONSIBILITY

This project is administered through CENTEC Corporation structure, as shown in Figure B-1. Day-to-day test program activities will be managed on-site by a CENTEC Senior Project Engineer in direct contact with CENTEC QA management personnel.

At the test site, the CENTEC engineer is responsible for implementing QA throughout the test program. The engineer conducts onsite evaluations to verify the degree of implementation, assures that appropriate QA records are kept, provides QA direction to the laboratory staff, and reports regularly to the Project Manager on the status of QA.

The Project Manager, Ed Comfort, is the Quality Assurance Officer. He continuously monitors the implementation of QA and provides feedback to the CENTEC engineer onsite and to CENTEC management. QA records kept by the engineer (onsite) and by the Quality Assurance Officer (offsite) serve as resources for preparing reports and documenting adherence to QA procedures and specifications.


CHAIRMAN AND PRESIDENT
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CURT GRINA
QUALITY ASSURANCE OFFICER
ED COMFORT
SENIOR PROJECT ENGINEERS
K. KENNEDY
C. ROBERTS

Figure B-1. Project Organization as Related to Corporate Structure

SECTION 4

QA OBJECTIVES FOR MEASUREMENT DATA IN TERMS OF PRECISION, ACCURACY, COMPLETENESS, REPRESENTATIVENESS AND COMPARABILITY

For each major measurement parameter specific QA objectives for precision, accuracy, and completeness are required. These objectives are detailed in Table B-1.

Care must be taken to assure that all measurements are representative of the media and conditions being measured. Proven techniques or methods are therefore used for all measurements.

Data quality objectives are based on accuracy and precision of each measurement parameter, as established in Table B-1. Data integrity will be validated through a series of inspections and tests described later in this plan.

Table B-1. Spray Painting Transfer Efficiency Precision, Accuracy and Completeness Objective

Measurement Parameter (Method)	Reference Method	Experimental Conditions	Precision (Std. Deviation)	Accuracy	Completeness
● Weight		Laboratory conditions	lab scale 0.01 g plat. scale 5 g	lab scale ±0.01 g plat. scale ±5 g	100% 100%
● Grounding	IEEE Std 32-1972 ANSI/IEEE Std 142-1972 ANSI C2	Laboratory conditions	—	—	100%
● Voltage	IEEE Std 4-1978	Laboratory conditions	0.05 kV	±0.1 kV	100%
● Units	ASTM E 380-76/ IEEE Std 268-1976	Laboratory conditions	—	—	100%
● Distance-length		Laboratory conditions	1/32 in	1/64 in	100%
● Time (Stopwatch, timer)	(See ASTM 1200-70)	Laboratory conditions	0.1 s	0.2 s	100%
● Wet Film Thickness	ASTM D-1212-79	Laboratory conditions	0.265 mil	0.85 mil	100%
● Dry Film Thickness	ASTM D-1005-51(1079)	Laboratory conditions	(2%) ±0.1 mil	2%	100%
● Viscosity (Ford cup)	ASTM D 1200-70(1976) ASTM D 2353-68(1978)		1.5 s	2 s	100% 100%
● Resistivity			0.1 MΩ	0.1 MΩ	100%
● Pressure			5%	Air atomized ±0.5 kPa Airless ±3.5 kPa	100%
● Temperature		Test conditions	0.1°C	0.1°C	
● Linear Air Velocity (rotating vane or heated wire anenometer)	ACGIH Recommended Practice, Section 9*	In accordance with NFPA 33	(3%)	±3%	100%
● Density	ASTM D 1475-60(1980)		±0.001 g/mL	0.002 g/mL	100%
● Wt% Solids	ASTM D 2369-81		(1.5%)	4.7%	100%
● Paint Sampling	ASTM D 3925		—	—	
● Condition in Container	ASTM D 3011-1		—	—	

---

*Industrial Ventilation - A Manual of Recommended Practice, American Conference of Governmental Industrial Hygenists, 1972.

SECTION 5

SAMPLING PROCEDURE

A description of the sampling procedure is provided in the Subtask Report, Appendix A, Draft Standard Test Method for Spray Painting Transfer Efficiency. The draft standard test method includes:

- A description of the test method, including references to standard methods
- Figures illustrating specific operations
- Description of sampling and test equipment
- Data sheets
- Other special conditions and considerations in performing the test

SECTION 6

SAMPLE CUSTODY

Sample custody procedures are addressed in Draft Standard Test Method for Spray Painting Transfer Efficiency, Subtask Report Appendix A. The CENTEC engineer and laboratory technician will check and sign all data sheets. The laboratory will retain all weighed foils, as described in the draft test method, until the data analysis is complete. CENTEC will retain all original data sheets.

SECTION 7

CALIBRATION PROCEDURES, ANALYTICAL PROCEDURES AND FREQUENCY

Calibration procedures, analytical procedures, and frequency requirements are included in Draft Standard Test Method for Spray Painting Transfer Efficiency, Subtask Report, Appendix A.

SECTION 8

DATA REDUCTION, VALIDATION, AND REPORTING

8.1 GENERAL

Data will be collected at the test laboratory under the guidance of a CENTEC engineer. The data will be collected and documented according to the requirements of the Draft Standard Test Method for Spray Painting Transfer Efficiency (Subtask Report, Appendix A). Equations for reducing the data are also contained in the draft standard test method. Figure B-2 shows the responsible parties for each data validation and reduction step.

8.2 DATA REDUCTION, VALIDATION, AND REPORTING

Data reduction will be performed using standard statistical practices as described in Draft Standard Test Method for Spray Painting Transfer Efficiency, Subtask Report, Appendix A. Any data generated by test runs with known discrepancies in performance will be labeled as suspect for later evaluation. Duplicate data for all suspect runs will be obtained whenever resources permit.

For each experimental design, the reduced data will be subjected to a series of t tests using studentized residuals to evaluate outliers. This evaluation will be performed onsite when 75 percent of a test series is complete. Outliers will be replaced by duplicate runs as resources permit. Any remaining outliers will be eliminated from the data set where possible without rendering the data set useless.

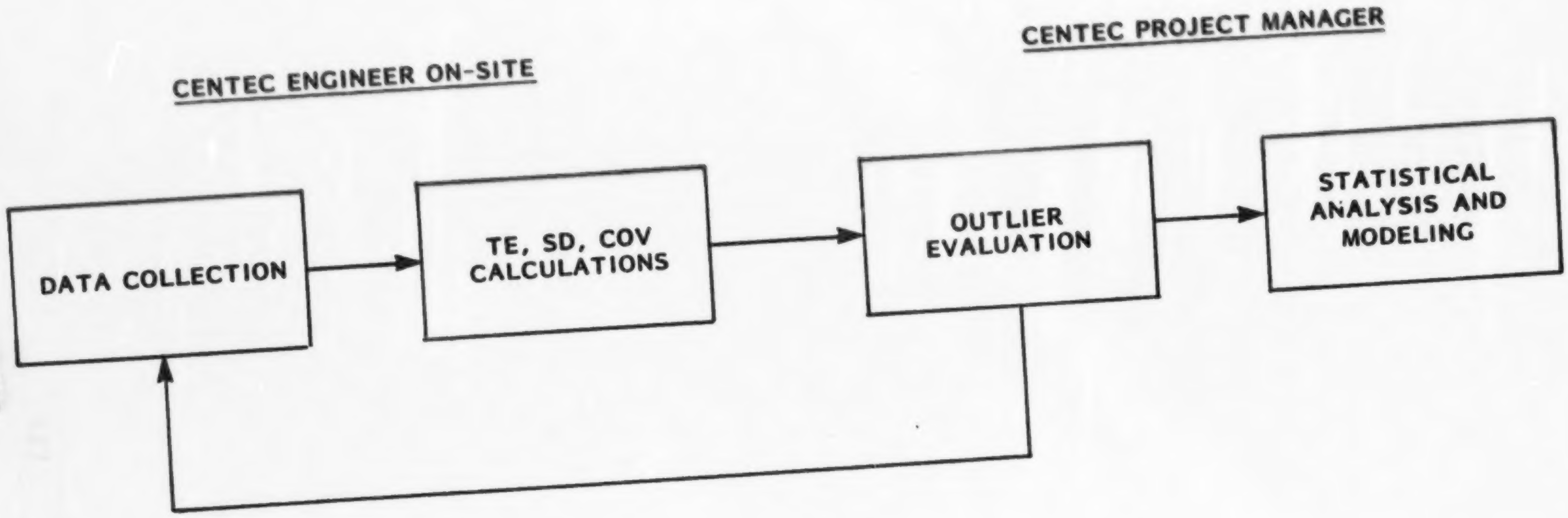
CENTEC ENGINEER ON-SITE
CENTEC PROJECT MANAGER
DATA COLLECTION
TE, SD, COV CALCULATIONS
OUTLIER EVALUATION
STATISTICAL ANALYSIS AND MODELING

Figure B-2. Data Validation Resposibilities

SECTION 9

INTERNAL QUALITY CONTROL CHECKS

Internal quality control checks are incorporated into the experimental design and Draft Standard Test Method for Spray Painting Transfer Efficiency (Subtask Report, Appendix A). These checks include a battery of replicates for each type of spray equipment to be tested. Calibration requirements also are specified in the Subtask Report, Appendix A. All data is subjected to two inspections for error (by the CENTEC engineer, and by a laboratory representative), with concurring signatures required on each data sheet.

SECTION 10

PERFORMANCE OF SYSTEM AUDITS

The performance of the TE tests will be monitored constantly as described in *Draft Standard Test Method for Spray Painting Transfer Efficiency*, Subtask Report, Appendix A.

SECTION 11

PREVENTATIVE MAINTENANCE

Certain preventative maintenance (PM) procedures must be followed to keep downtime to a minimum. Most PM practices are recommended by the manufacturer to the spray equipment user. These practices include keeping the spray equipment and spray area clean, handling equipment carefully to avoid damage, and using appropriate equipment for the given job. These general practices must be observed to prevent inadvertent deterioration of spray equipment condition and to minimize downtime.

In addition to these PM practices, extra electrodes and air caps should be kept on hand. Ample supplies for performing TE tests should be available to avert shortages. These include foil, paint, tape, solvent, and others outlined in the draft standard TE test method.

SECTION 12

SPECIFIC ROUTINE PROCEDURES TO ASSESS DATA PRECISION, ACCURACY AND COMPLETENESS

After the spray painting system is operational, performance audits will be conducted to assure continued acceptable precision and accuracy during testing. It is the nature of the experimental design for this program that TE results cannot be tested for outliers until three-quarters of a test series is complete. To minimize the likelihood of obtaining poor TE results prior to outlier analyses, performance audits are required twice daily for each major measurement contributing to TE:

- Net solids on target, g
- Conveyor speed, cm/s
- Paint weight fraction solids
- Paint mass flow rate, g/s
- Effective target width, cm

These measurements are subject to the precision, accuracy, and completeness criteria in Table B-1. They will be audited for precison and accuracy at the beginning and completion of each test day. Periodic audits also may be conducted during the test day as deemed appropriate by either the laboratory technician or CENTEC engineer on site. Performance audit requirements are detailed in Table B-2 and in the Draft Standard Test Method for Spray Painting Transfer Efficiency.

TABLE B-2. PERFORMANCE AUDIT REQUIREMENTS

Measurement Parameter (units)	Performance Audit Method	When Required
Net solids on target(g)	o Measure known control weight	A,B,C,D
Conveyor speed (cm/s)	o Blank run using electronic timer o Chalk mark and stopwatch	A,B,C,D
Paint weight fraction solids	o Conduct duplicate analyses per ASTM 2369 at manufacturers recommended cure schedule	A,B,C,D
Paint mass flow rate (g/s)	o Spraying, using stopwatch and scales	A,B,C,D
Effective target width	o Ruler or tape measure	C

A = Start of each day
B = At change of paint or spray equipment
C = As requested by lab technician or eng.
D = End of each day

The precision and/or accuracy of the total measurement system will be documented at least twice daily. Problems identified by the performance audit will be corrected before continuing with the test program.

Completeness requirements are audited continuously and automatically by the dual check off procedures required on each data sheet in the draft standard test method.

SECTION 13

CORRECTIVE ACTION

Performance audits are required twice daily for each major measurement contributing to TE. Should any measurement not meet the precision or accuracy requirements laid out in Table B-1, corrective action must be taken. Corrective action includes recalibration, repair, or replacement of the measurement system in question. The CENTEC engineer on site is responsible for initiating the appropriate corrective action, with concurrence from the participating required in writing in the next QA report to management.

Corrective action may also be taken to replace data identified as erroneous by the required data outlier analysis. The CENTEC Project Manager is responsible for initiating corrective action to replace outlier data.

Other corrective action may be taken at the request of onsite CENTEC or laboratory personnel whenever suspect or undocumented conditions occur. The CENTEC engineer is responsible for all such corrective actions.

SECTION 14

QUALITY ASSURANCE REPORTS TO MANAGEMENT

The CENTEC engineer on site will report daily via telephone to the CENTEC Project Manager regarding the results of all performance audits, measurement system accuracy, and measurement system precision. Significant QA problems and recommended solutions will be discussed. Brief records of these reports will be kept for later inclusion in the final test report QA section.

APPENDIX C

AAC TEST EQUIPMENT AND PAINT SPECIFICATIONS

Data Sheet 1

Test Equipment Specifications

Test Date: 2-2-90
Test No.: AAC-6
Data by/Checked by: DZ / KCR

A. Weight Percent Solids Measurement Equipment	
1. Laboratory Scales	
a. Manufacturer	Precisa
b. Model No.	240-21
c. Serial No.	M574227
d. Capacity, g	0-300/0-3000 GRAMS
e. Rated accuracy, g	.01G Resolution/.1G Resolution
2. Foil Dishes	
a. Type	Aluminum
b. Size	58mm round
3. Syringe	
a. Type	Glass
b. Capacity, mL	5
4. Solvent Type	Xylene
B. Conveyor Speed Measurement Equipment	
1. Rule	
a. Type	conventional
b. Graduations	1/32"
2. Electronic Timer	
a. Type	Electro-Mechanical Digital
b. Manufacturer	~~Precision Scientific Co.~~ CRAMER
c. Model No.	~~69230~~ 636.0
d. Serial No.	- [illegible]
e. Rated accuracy, s	KS ~~.1 sec.~~
C. Mass Flow Measurement Equipment	
1. Platform Scales	
a. Manufacturer	Mass Flow Meter: Micromotion
b. Model No.	C12AF with D10 Rt Indicator
c. Serial No.	7495
d. Capacity, kg	0 to 1000 G/Min. .68 to 13 KG/Min.
e. Rated accuracy, g	+1 - .4% Reading
2. Stopwatch	
a. Manufacturer	Cronus Precision Products, Inc.
b. Model No.	-
c. Serial No.	-
d. Rated accuracy, s	.01
D. Target Foil	
1. Type	Alum. Alloy 1145-
2. Nominal Thickness, mils	1.5
3. Temper	Medium
E. Wet Film Measurement Equipment	
a. Manufacturer	Gardco 0-4 Mils
b. Model No.	Precision Direct Reading
F. Dry Film Measurement Equipment	
a. Manufacturer	DeFelsko Corp.
b. Model No.	Positector 2000 .1 mils Accuracy

6.3 Select coating. The same coating shall be used for all tests in this program. Using Data Sheet 2, document the paint characteristics. Paint characteristics shall be documented daily, at each addition of paint, and at other times as requested by the CENTEC engineer or GRACO representative. Again, check your information and sign the form.

Data Sheet 2

Paint Specifications

Test Date:	Test No.:	Data by/Checked by:
2/9	ABC 6	DJ / KCK

1. Paint Type	Black Enamel (Graco #077-001)
2. Resin Type	Alkyd Base
3. Manufacturer	Reliance
4. Manufacturer's Paint ID No.	210-3150
5. Lot No.	Batch #1
6. Color	Black
7. Recommended Cure Schedule	17 min. @ 329 °F
8. Viscosity (uncut)	Minimum 66 sec. #2ZAHN @ 77°F sec.# Ford Cup @ °F
9. Reducing Solvent	Xylol ~~or MEK~~
10. Vol. of Solvent Put into Vol. Paint	est. ratio / (vol) solvent in y (vol) paint
11. Viscosity - Spray (cut)*	* 29.3 sec.# 2 Shell ~~Ford~~ Cup @ 25° ~~°F~~ C - (ASTM)
12. Wt./Gallon - Spray	spgr .915 ~~lbs/gal.~~
13. Wt. Solids - Spray	— %
14. Resistivity or Conductance	22 MΩ/in² μA

Beckman Megohmmeter Model L-8

*Use ASTM D-2353-68, ASTM D-1200-70, or ASTM D-3794 part 6.

* (29.3 s. #~~5~~2 Shell dynamic visc)

Data Sheet 3

Paint Spray and Peripheral Equipment Specifications

Test Date:	Test No.:	Data by/Chkd by:
2/8/84	AHC 6	KCK/[illegible]

A. Paint Supply Tank

1. Type	Pressure Tank
2. Manufacturer	Graco
3. Model No.	[illegible]
4. Serial No.	—
5. Rated Capacity, gal	5 Gal.

B. Paint Spray Equipment

1. Type	Hand Held Air Spray Conventional
2. Manufacturer	Graco
3. Model No.	Model 800 [illegible]
4. Serial No.	— None
5. Rated Capacity, cc/min	n/a
6. Air Cap	[illegible]
7. Fluid Tip	[illegible]
8. Needle	02

C. Paint Spray Booth

1. Type	Dynaprecipitor Water Wash
2. Manufacturer	Binks
3. Model No.	807605 (Dwg. No.)
4. Serial No.	-
5. Rated Capacity, cfm	-

D. Conveyor

1. Type	Overhead
2. Manufacturer	Reliance Electric Co.
3. Model No.	Minpak V.S Drive
4. Serial No.	-

E. Forced Draft Oven

1. Type	Forced Air Gas Oven
2. Manufacturer	Drying Systems Company
3. Model No.	-
4. Serial No.	12941 Controller 1-2941-A Oven

F. Paint Heaters

1. Type	n/a
2. Manufacturer	n/a
3. Model No.	n/a
4. Serial No.	n/a

APPENDIX D

AAE TEST EQUIPMENT AND PAINT SPECIFICATIONS

Data Sheet 1

Test Equipment Specifications

Test Date:	Test No.:	Data by/Checked by:
2/14/84	AAE-22	Emil / DK.

A. Weight Percent Solids Measurement Equipment	
1. Laboratory Scales	
a. Manufacturer	Precisa
b. Model No.	240-21
c. Serial No.	M574227
d. Capacity, g	0-300/0-3000 GRAMS
e. Rated accuracy, g	.01G Resolution/.1G Resolution
2. Foil Dishes	
a. Type	Aluminum
b. Size	58mm round
3. Syringe	
a. Type	Glass
b. Capacity, mL	5
4. Solvent Type	Xylol
B. Conveyor Speed Measurement Equipment	
1. Rule	
a. Type	conventional
b. Graduations	1/32"
2. Electronic Timer	
a. Type	Electro-Mechanical Digital
b. Manufacturer	~~Precision Scientific Co.~~ Cramer
c. Model No.	~~60230~~ 636W
d. Serial No.	- 104BTM
e. Rated accuracy, s	~~.1 sec.~~
C. Mass Flow Measurement Equipment	
1. Platform Scales	
a. Manufacturer	Mass Flow Meter: Micromotion
b. Model No.	C12AF with D10 Rt Indicator
c. Serial No.	7495
d. Capacity, kg	0 to 1000 G/Min. .68 to 13 KG/Min.
e. Rated accuracy, g	+1 - .4% Reading
2. Stopwatch	
a. Manufacturer	Cronus Precision Products, Inc.
b. Model No.	-
c. Serial No.	-
d. Rated accuracy, s	.01
D. Target Foil	
1. Type	Alum. Alloy 1145-0
2. Nominal Thickness, mils	1.5
3. Temper	Medium
E. Wet Film Measurement Equipment	
a. Manufacturer	Gardco 0-4 Mils
b. Model No.	Precision Direct Reading
F. Dry Film Measurement Equipment	
a. Manufacturer	DeFelsko Corp.
b. Model No.	Positector 2000 .1 mils Accuracy

6.3 Select coating. The same coating shall be used for all tests in this program. Using Data Sheet 2, document the paint characteristics. Paint characteristics shall be documented daily, at each addition of paint, and at other times as requested by the CENTEC engineer or GRACO representative. Again, check your information and sign the form.

Data Sheet 2

Paint Specifications

Test Date: 2/14/84

Test No.: ME-22

Data by/Checked by: EBR/DK

1. Paint Type	Black Enamel (Graco #077-001)
2. Resin Type	Alkyd Base
3. Manufacturer	Reliance
4. Manufacturer's Paint ID No.	210-3150
5. Lot No.	BATCH #2
6. Color	Black
7. Recommended Cure Schedule	17 min. @ 329 °F
8. Viscosity (uncut)	Minimum 66 sec. #2ZAHN @ 77°F sec.@ ~~32 Ford~~ Cup @ °F
9. Reducing Solvent	Xylol ~~or MEK~~
10. Vol. of Solvent Put into Vol. Paint	1/1 (vol) solvent in (vol) paint
11. Viscosity - Spray (cut)*	30-30 sec.@ #2 Shell ~~Ford~~ Cup @ 75°F
12. Wt./Gallon - Spray	SG = .975 lbs/gal
13. Wt. Solids - Spray	— %
14. Resistivity or Conductance	96 MΩ μA

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*Use ASTM D-2353-68, ASTM D-1200-70, or ASTM D-3794 part 6.

Data Sheet 3

Paint Spray and Peripheral Equipment Specifications

Test Date:	Test No.:	Data by/Chkd by:
2/14/87	AAE-72	DK. EVR

A. Paint Supply Tank

1. Type	Pressure Tank
2. Manufacturer	Graco
3. Model No.	210-393
4. Serial No.	-
5. Rated Capacity, gal	.5 gal.

B. Paint Spray Equipment

1. Type	Hand Held Air Atomized Electrostatic
2. Manufacturer	Graco
3. Model No.	45 4000 215870
4. Serial No.	# 61183
5. Rated Capacity, cc/min	35.5 - 71.0
6. Air Cap	177033
7. Fluid Tip	176976
8. Needle	215864

C. Paint Spray Booth

1. Type	Dynaprecipitor Water Wash
2. Manufacturer	Binks
3. Model No.	807605 (Dwg. No.)
4. Serial No.	-
5. Rated Capacity, cfm	-

D. Conveyor

1. Type	Overhead
2. Manufacturer	Reliance Electric Co.
3. Model No.	Minpak V.S Drive
4. Serial No.	-

E. Forced Draft Oven

1. Type	Forced Air Gas Oven
2. Manufacturer	Drying Systems Company
3. Model No.	-
4. Serial No.	12941 Controller 1-29 , Oven

F. Paint Heaters

1. Type	n/a
2. Manufacturer	n/a
3. Model No.	n/a
4. Serial No.	n/a

APPENDIX E

ALC TEST EQUIPMENT AND PAINT SPECIFICATIONS

Data Sheet 1

Test Equipment Specifications

Test Date:	Test No.:	Data by/Checked by:
2-22-94	ALC 22	EHe / G.E.O

A. Weight Percent Solids Measurement Equipment	
1. Laboratory Scales	
a. Manufacturer	Precisa
b. Model No.	240-21
c. Serial No.	M574227
d. Capacity, g	0-300/0-3000 GRAMS
e. Rated accuracy, g	.01G Resolution/.1G Resolution
2. Foil Dishes	
a. Type	Aluminum
b. Size	58mm round
3. Syringe	
a. Type	Glass
b. Capacity, mL	5
4. Solvent Type	Xylol
B. Conveyor Speed Measurement Equipment	
1. Rule	
a. Type	conventional
b. Graduations	1/32"
2. Electronic Timer	
a. Type	Electro-Mechanical Digital
b. Manufacturer	Precision Scientific Co.
c. Model No.	69230
d. Serial No.	-
e. Rated accuracy, s	.1 sec.
C. Mass Flow Measurement Equipment	
1. Platform Scales	
a. Manufacturer	Mass Flow Meter: Micromotion
b. Model No.	C12AF with D10 Rt Indicator
c. Serial No.	7495
d. Capacity, kg	0 to 1000 G/Min. .68 to 13 KG/Min.
e. Rated accuracy, g	±1 - .4% Reading
2. Stopwatch	
a. Manufacturer	Cronus Precision Products, Inc.
b. Model No.	-
c. Serial No.	-
d. Rated accuracy, s	.01
D. Target Foil	
1. Type	Alum. Alloy 1145-0
2. Nominal Thickness, mils	1.5
3. Temper	Medium
E. Wet Film Measurement Equipment	
a. Manufacturer	Gardco 0-4 Mils
b. Model No.	Precision Direct Reading
F. Dry Film Measurement Equipment	
a. Manufacturer	DeFelsko Corp.
b. Model No.	Positector 2000 .1 mils Accuracy

6.3 Select coating. The same coating shall be used for all tests in this program. Using Data Sheet 2, document the paint characteristics. Paint characteristics shall be documented daily, at each addition of paint, and at other times as requested by the CENTEC engineer or GRACO representative. Again, check your information and sign the form.

Data Sheet 2

Paint Specifications

Test Date:	Test No.:	Data by/Checked by:
2-22-84	Acc 22	SHC / GEO.

1.	Paint Type	Black Enamel (Graco #077-001)
2.	Resin Type	Alkyd Base UN1263 2-8-84
3.	Manufacturer	Reliance
4.	Manufacturer's Paint ID No.	43217 270129 210-3150
5.	Lot No.	UN1263 2-8-84
6.	Color	Black
7.	Recommended Cure Schedule	17 min. @ 329 °F
8.	Viscosity (uncut)	Minimum 66 sec. #2ZAHN @ 77°F sec.# Ford Cup @ °F
9.	Reducing Solvent	Xylol
10.	Vol. of Solvent Put into Vol. Paint	(vol) solvent in (vol) paint
11.	Viscosity - Spray (cut)*	25.04 sec.# 3 ~~Ford~~ SHELL Cup @ °F
12.	Wt./Gallon - Spray	59 .925 lbs/gal
13.	Wt. Solids - Spray	%
14.	Resistivity or Conductance	320 MΩ/cm mA

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*Use ASTM D-2353-68, ASTM D-1200-70, or ASTM D-3794 part 6.

Data Sheet 3

Paint Spray and Peripheral Equipment Specifications

Test Date: 2-22-94

Test No.: ACC 22

Data by/Chkd by: Sthc/GEO

A. Paint Supply Tank
  1. Type ~~[illegible]~~ air-powered 30:1 ratio
  2. Manufacturer Graco
  3. Model No. 207707
  4. Serial No. ~~[illegible]~~ 13D
  5. Rated Capacity, gal ~~[illegible]~~ 1 gal/min max

B. Paint Spray Equipment
  1. Type Air-assist Conventional
  2. Manufacturer Kremlin
  3. Model No. AVG 200663
  4. Serial No.
  5. Rated Capacity, cc/min 5000 psig work press.
  6. Air Cap — /
  7. Fluid Tip ? — .013
  8. Needle —

C. Paint Spray Booth
  1. Type Dynaprecipitor Water Wash
  2. Manufacturer Binks
  3. Model No. 807605 (Dwg. No.)
  4. Serial No. -
  5. Rated Capacity, cfm -

D. Conveyor
  1. Type Overhead
  2. Manufacturer Reliance Electric Co.
  3. Model No. Minpak V.S Drive
  4. Serial No. -

E. Forced Draft Oven
  1. Type Forced Air Gas Oven
  2. Manufacturer Drying Systems Company
  3. Model No. -
  4. Serial No. 129- Controller 1-2941-A Oven

F. Paint Heaters
  1. Type n/a
  2. Manufacturer n/a
  3. Model No. n/a
  4. Serial No. n/a

APPENDIX F

ALE TEST EQUIPMENT AND PAINT SPECIFICATIONS

Data Sheet 1

Test Equipment Specifications

Test Date: 7/18/84

Test No.: ALE 29

Data by/Checked by:

A. Weight Percent Solids Measurement Equipment	
1. Laboratory Scales	
a. Manufacturer	Precisa
b. Model No.	240-21
c. Serial No.	M574227
d. Capacity, g	0-300/0-3000 GRAMS
e. Rated accuracy, g	.01G Resolution/.1G Resolution
2. Foil Dishes	
a. Type	Aluminum
b. Size	58mm round
3. Syringe	
a. Type	Glass
b. Capacity, mL	5
4. Solvent Type	Xylol
B. Conveyor Speed Measurement Equipment	
1. Rule	
a. Type	conventional
b. Graduations	1/32"
2. Electronic Timer	
a. Type	Electro-Mechanical Digital
b. Manufacturer	Precision Scientific Co.
c. Model No.	69230
d. Serial No.	-
e. Rated accuracy, s	.1 sec.
C. Mass Flow Measurement Equipment	
1. Platform Scales	
a. Manufacturer	Mass Flow Meter: Micromotion
b. Model No.	C12AF with D10 Rt Indicator
c. Serial No.	7495
d. Capacity, kg	0 to 1000 G/Min. .68 to 13 KG/Min.
e. Rated accuracy, g	±1 - .4% Reading
2. Stopwatch	
a. Manufacturer	Cronus Precision Products, Inc.
b. Model No.	-
c. Serial No.	-
d. Rated accuracy, s	.01
D. Target Foil	
1. Type	Alum. Alloy 1145-0
2. Nominal Thickness, mils	1.5
3. Temper	Medium
E. Wet Film Measurement Equipment	
a. Manufacturer	Gardco 0-4 Mils
b. Model No.	Precision Direct Reading
F. Dry Film Measurement Equipment	
a. Manufacturer	DeFelsko Corp.
b. Model No.	Positector 2000 .1 mils Accuracy

6.3 Select coating. The same coating shall be used for all tests in this program. Using Data Sheet 2, document the paint characteristics. Paint characteristics shall be documented daily, at each addition of paint, and at other times as requested by the CENTEC engineer or GRACO representative. Again, check your information and sign the form.

Data Sheet 2

Paint Specifications

Test Date:	Test No.:	Data by/Checked by:
2/27/84	AIE 29	ACK DJK

1. Paint Type: Black Enamel (Graco #077-001)
2. Resin Type: Alkyd Base
3. Manufacturer: Reliance
4. Manufacturer's Paint ID No.: 210-3150
5. Lot No.: see note
6. Color: Black
7. Recommended Cure Schedule: ~~30~~ XT min. @ ~~300~~ ~~229~~ °F 340°F 20min
8. Viscosity (uncut): Minimum 66 sec. #2ZAHN @ 77°F
   sec.# Ford Cup @ °F
9. Reducing Solvent: Xylol ~~[illegible]~~ (& ethyl [illegible] + Mineral Spir[illegible]
10. Vol. of Solvent Put into Vol. Paint: (vol) solvent in
    10 [illegible] (vol) paint
11. Viscosity - Spray (cut)*: sec.# Ford Cup @ °F
12. Wt./Gallon - Spray: 5.6 .920 ~~lbs/gal~~
13. Wt. Solids - Spray: %
14. Resistivity or Conductance: 25 MΩ/cm ~~[illegible]~~

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*Use ASTM D-2353-68, ASTM D-1200-70, or ASTM D-3794 part 6.

NOTE:
Paint label on drum
43317 E70129
Black Baking Enamel
P/N 077-001
UNi 263 2/8/84

EPA 25.49 Shell #3 at 78°
Graco 25.58 shell #3 " "

Data Sheet 3

Paint Spray and Peripheral Equipment Specifications

Test Date:	Test No.:	Data by/Chkd by:
7/23/84	002 ALE	KCK/D.Y

A. Paint Supply Tank

1. Type	10 gal, dbl reg
2. Manufacturer	GRACO
3. Model No.	n/a
4. Serial No.	n/a
5. Rated Capacity, gal	10 gal

B. Paint Spray Equipment

1. Type	Airless Electrostatic
2. Manufacturer	Graco
3. Model No.	AL 4000
4. Serial No.	P/N 217081
5. Rated Capacity, cc/min	S/N 2758 Series A4B
6. ~~Air Cap~~	611, 613, 615
7. Fluid Tip	
8. Needle	see test matrix

C. Paint Spray Booth

1. Type	Dynaprecipitor Water Wash
2. Manufacturer	Binks
3. Model No.	807605 (Dwg. No.)
4. Serial No.	-
5. Rated Capacity, cfm	-

D. Conveyor

1. Type	Overhead
2. Manufacturer	Reliance Electric Co.
3. Model No.	Minpak V.S Drive
4. Serial No.	-

E. Forced Draft Oven

1. Type	Forc[illegible] Air Gas Oven
2. Manufacturer	Dryi[illegible] Systems Company
3. Model No.	-
4. Serial No.	12941 Controller 1-2941-A Oven

F. Paint Heaters

1. Type	n/a
2. Manufacturer	n/a
3. Model No.	n/a
4. Serial No.	n/a

207-707 Model Pump (Paint)
K3D 30:1 Series

APPENDIX G

Glossary of Statistical Terms

Regression

The procedure of fitting a model to a set of data using the method of least squares. The product is a prediction equation for predicting a dependent response as a function of independent "input" variables.

Residuals

The error in fit of a regression equation. The residual is the difference between the observed response and a predicted response from the regression model.

t-tests

t-tests are used in the present context to test the hypothesis that a regression coefficient is zero. The t-statistic is a ratio

$$t = \frac{\text{regression coefficient}}{\text{standard error of coefficient}}$$

Small values of t are evidence of a coefficient that does not differ significantly from zero.

F-tests

F-tests are used in a manner very similar to the t-tests. For a specific regression coefficient, and thus for a particular variable, the F-statistic represents the ratio of the variance explained by the variable being tested to the variance attributed to experimental error.

Significance level (p value)

The significance level is used in the context of significance testing. If a regression coefficient (or a model variable) is significant at the 0.02 level, the value 0.02 is the probability of obtaining a t-statistic (or F) as large as that observed, when in fact the model variable plays absolutely no role in the system. In other words, a p value is the probability of obtaining such information due to chance alone. Clearly, a small p value is evidence of a strong model term or variable.

Standard Deviation

A standard deviation is a measure of spread in a statistical distribution or a set of data. Given $x_1, x_2, \ldots, x_n$, observations in a set of data and $\bar{x}$, the mean, the sample standard deviation is given by

$$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i-\bar{x})^2}{n-1}}$$

R^2 (Coefficient of Determination)

The coefficient of determination R^2 is a measure of quality of fit of a fitted model. The statistic R^2 is defined as

$$R^2 = \frac{\text{variation in response explained by model}}{\text{variation in response observed}}$$

Confidence Limits on Mean Response

In a regression context, the 95% confidence limits on the mean response represent "bounds" around the fitted regression that are defined such that

> "we are 95% confident that the mean response, at the data locations in question, is covered by the bounds."

Lack of Fit Test

The lack of fit test is an F-test for ascertaining whether or not a fitted model is adequate. The test essentially tests for the significance of higher order terms in the regression. If the F-statistic is nonsignificant, the conclusion is that there is no evidence that a more complicated model would improve the regression.

Dummy Variables

The use of dummy variables is a standard way of accommodating "categories" in a regression situation that also contains the ordinary continuous variables.